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by the
Ontario Geological Survey

edited by R.B. Barlow, M.E. Cherry, A.C. Colvine, Burkhard O. Dressler, and Owen L. White

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FOREWORD

During 1987, the Ontario Geological Survey carried out a large number of independent geoscience studies. In addition, studies were undertaken in cooperation with regional geological staff, personnel from universities, and private consulting firms. Special Geoscience programs were also undertaken in several areas under the Canada-Ontario Mineral Development (COMDA-ERDA) Agreement and in the Black River-Matheson (BRIM) and Wawa areas. Project involvement by the various participants is summarized in the individual reports. Separate funding for a number of regional stimulation projects was provided and funding acknowledgments are included in the individual summaries.

The locations of the areas investigated are compiled on two maps of the province at the beginning of this report. Preliminary results of field work and other research are outlined in this summary, which contains reports prepared by leaders and principal investigators for each of the projects. In these reports, some emphasis has been placed on the economic mineral resource aspects of the different investigations. The aim of the Ontario Geological Survey in producing this summary immediately following the field season, is to provide quick access to new information for mineral resource evaluation of these areas, which will be of value in current mineral exploration and resource planning. In addition, the wide spectrum of research in this report is of interest to the geoscience community as a whole.

Survey geoscientists will conduct more detailed research and analysis of the field work data through the winter and will be preparing reports on these investigations for publication. In the interim, uncoloured preliminary geoscience maps with comprehensive marginal notes will be released for distribution, mainly during the winter of 1986-1987. Notices of the releases will be mailed to all persons or organizations on the Mineral Resources Group publication release notification list, and will be published in the technical journals and other media.

V.G. Milne

Director

Ontario Geological Survey

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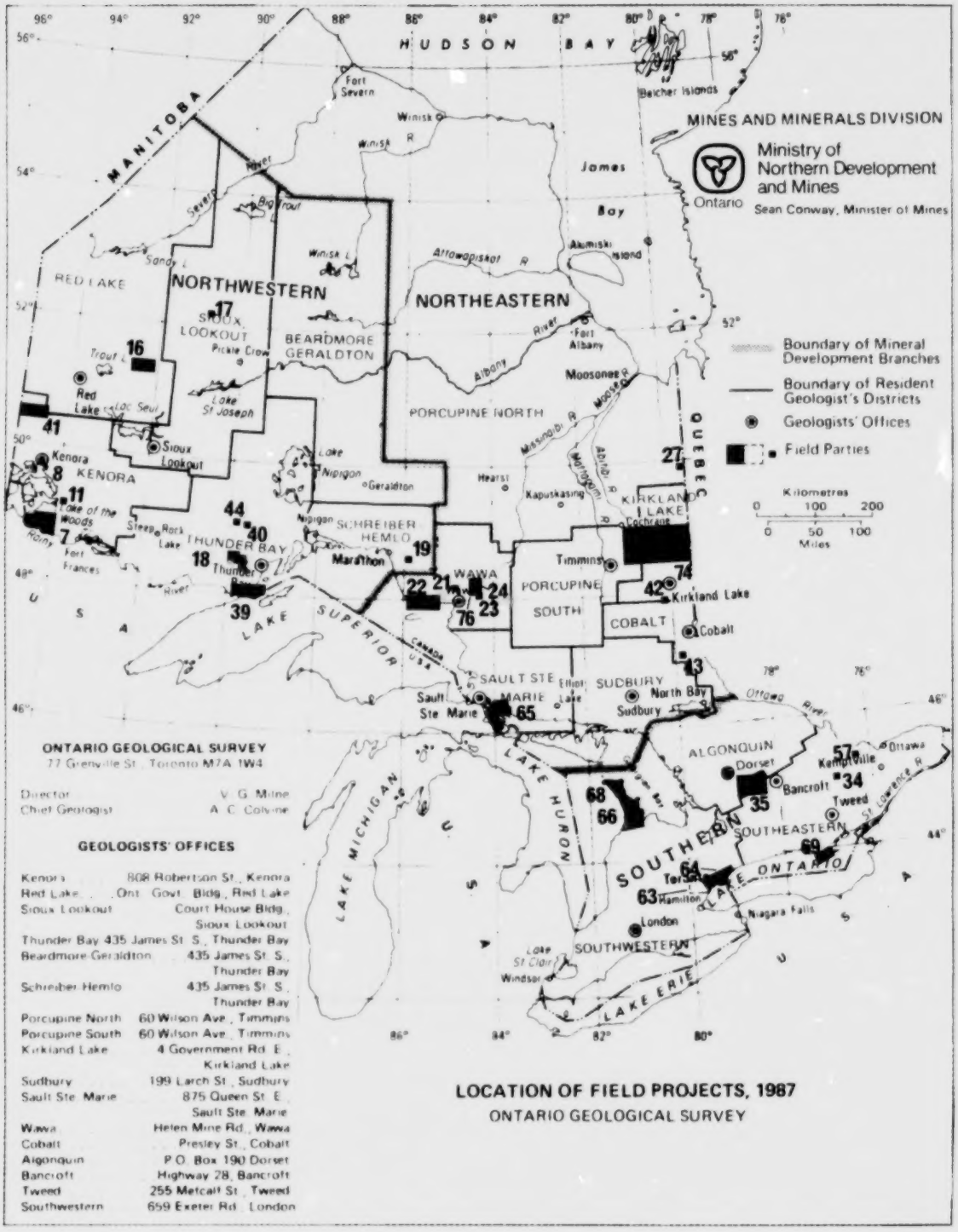
CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS.

CONVERSION FROM SI TO IMPERIAL			CONVERSION FROM IMPERIAL TO SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.103 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight perton (short)	0.05	ounces (troy) per ton (short)

Note. Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in cooperation with the Coal Association of Canada.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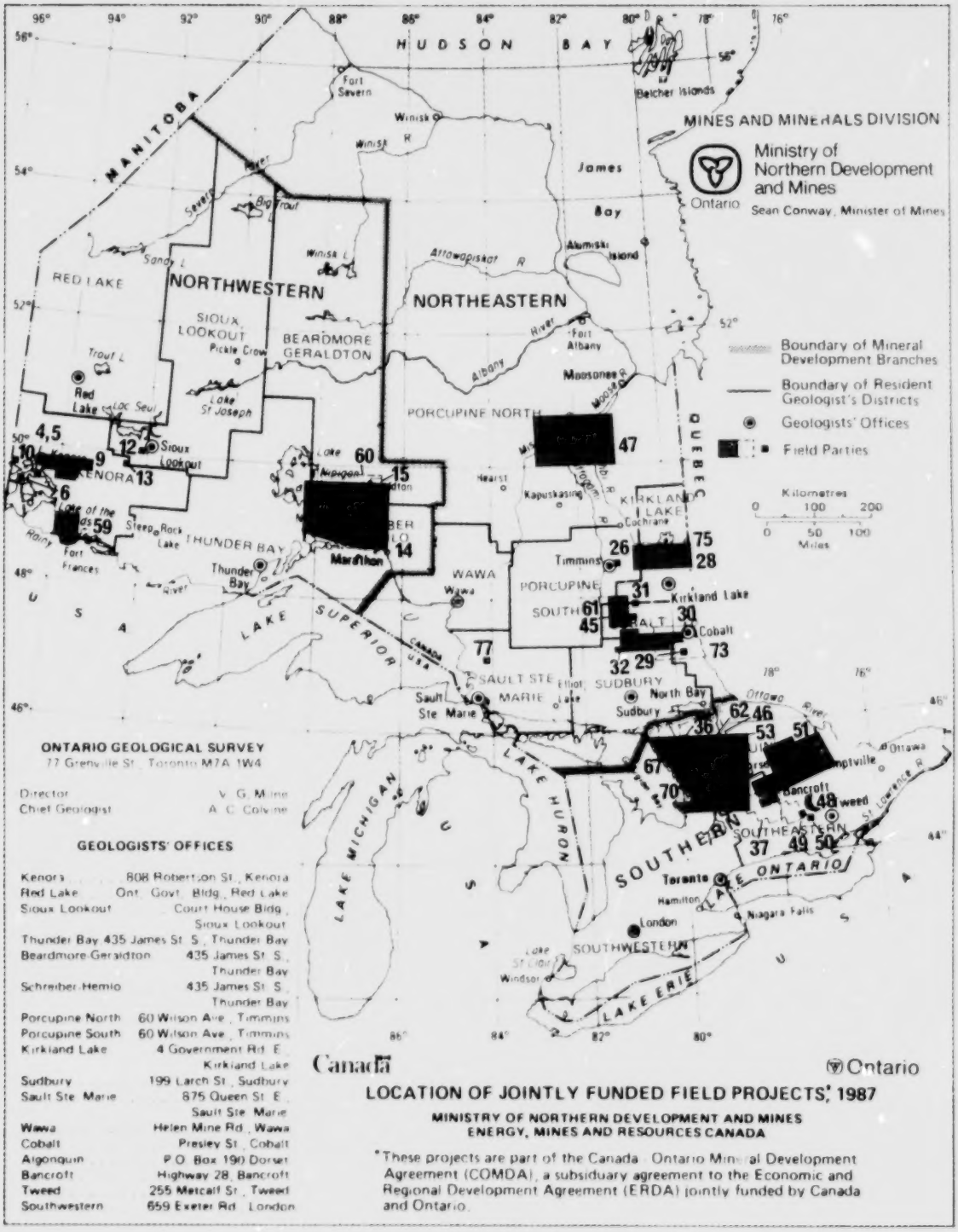
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*These projects are part of the Canada - Ontario Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) jointly funded by Canada and Ontario.

PRECAMBRIAN GEOLOGY PROGRAMS

001. Summary of Activities, 1987, Precambrian Geology Section

A.C. Colvine

Chief Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

Readers of previous Summaries of Field Work will notice an absence from this volume of a separate section describing the activities of the Mineral Deposits Section. This absence is due to the merger, in December 1986, of the former Mineral Deposits and Precambrian Geology Sections into a single Precambrian Geology Section, with the mandate to study all aspects of the geology and mineralization of the Precambrian Shield in Ontario. This merger reflects the need to better integrate the work of the two former groups, and does not represent a reduction in commitment to the objectives of either group. There are no major changes in program emphasis reflected in the summaries that follow: high quality, field-based research and documentation of the geology of the Shield continues to be our principal goal, and the important mineral exploration industry continues to be our principal client group.

The main change resulting from the merger is in the organization of, and the approach to, the various projects: the merger allows individuals working in a single area, or on similar topics, to be formally linked into working groups. Just as studies of mineralization cannot be conducted without consideration of its areal geological framework, detailed (1:15 840 scale) geological mapping must be conducted with an understanding of the regional geological framework. The working groups provide this essential breadth of understanding, as well as the diversity of skills necessary to advance our overall understanding of Shield geology.

One of the most important group initiatives begun in 1987 is the preparation of a volume and associated 1:1 000 000 scale maps of the Geology of Ontario, currently scheduled for completion in 1991, to coincide with the centennial of the Ontario Geological Survey and its predecessors. P.C. Thurston is coordinating this major project, as discussed in his extended summary of activities (Article 002). This project will not only provide an updated synthesis of our current level of understanding of the geology of the Province, but will also identify areas of inadequate geological knowledge. As such, it will become an integral part of planning future programs.

A second major new initiative in 1987, which is not reported independently in this volume, is a project to develop and publish completely revised compilation series maps, at a scale of 1:250 000. These maps have always been widely purchased and used by the mineral exploration industry. The updated maps will reflect advances in our understanding of Shield geology, and will also contain greatly enhanced mineral deposit information beyond that displayed on the present maps. Revision of the Atikokan-Lakehead area (NTS sheets 52A, B, G, and H) is currently in progress.

Where possible, the summaries have been grouped to reflect working groups already in place, and individual contributions to a broad-based program have been linked by a general introduction. Summaries fall into several broad categories, depending on whether they are related more to geographic or to thematic topics.

Multi-disciplinary programs, incorporating detailed and regional bedrock mapping, structural and stratigraphic studies, and mineral deposits studies, have been operating for several years in the Lake of the Woods area of the western Wabigoon Subprovince, in the Beardmore-Geraldton belt, the Wawa greenstone belt, and in the Grenville Province. This year's summaries of individual projects in these areas reflect the maturity of the programs. A new program in the Abitibi greenstone belt was begun in 1987: this program will be expanded in the coming year as the understanding of this large, well-preserved, and economically important greenstone belt is updated. To assist this project, a cooperative research project with the University of Toronto has been established to conduct a deep crustal reflection seismic transect across the belt during the Fall of 1987.

Several of the summaries report individual projects that are nearing completion, for example the study of the Hemlo gold camp, and mapping in the Birch Lake area of the Uchi Subprovince. Other summaries are preliminary reports of projects begun in 1987, for example the geology of the Horseshoe Lake greenstone belt.

The Section continued in 1987 to document the occurrence of Platinum Group Element (PGE) mineralization in Ontario, and expanded the program to improve our understanding of the rocks in which the PGE's are known to occur. Projects in this commodity-based program were carried out in several Archean terrains, as well as in early and late Proterozoic terrains.

Requests from the minerals industry for information about industrial minerals continued to be frequent in 1987. Projects to increase the knowledge of these commodities, operated by the Section and by Regional Offices of the Mines and Minerals Division, include studies of kaolinite, talc, wollastonite, fluorite, graphite, rare earth elements, and building stone. Studies of industrial minerals will continue as a major program of the Section in the coming year.

The rapidly growing use of modern computer technology in geology and mineral exploration is reflected in the final three summaries. The Section maintains a number of microcomputer-based computer programs for manipulation and presentation of geological data; revisions of current programs and development of new programs are continuing projects. The very large, publically accessible, PETROCH database, maintained by the Geoscience Data Centre of the Ontario Geological Survey, is being used in a project to develop new geochemical classification schemes for volcanic rocks.

The use of remote sensing techniques in exploring for mineralization is reported as a result of a collaboration with the Ontario Centre for Remote Sensing (*see* Article 057). The application of remote sensing techniques to geological mapping is being investigated in a new program initiative under the direction of N.F. Trowell.

Conspicuous by its absence is an emphasis on the geology of Archean gold deposits, which has been the focus of the former Mineral Deposits Section since 1982. As outlined in last year's Summary of Field Work, this program comprises two parts: development of a genetic model, through detailed studies of known gold mineralization; and testing and revision of this model, through its application to areas not known to contain significant gold mineralization. The natural progression of this work is that it be incorporated into all new mapping studies. Hence, this year, the geological framework pertinent to gold mineralization is contained in individual summaries.

During 1987, geologists of the Section published numerous internal and external papers on the geology and mineralization of Ontario. Staff members presented papers or posters at Regional Geoscience Seminars held in Kenora, Thunder Bay, and Timmins, and at provincial, national, and international conferences and symposia. These included symposia, conferences, or short courses on platinum group elements (Ontario), mafic intrusions (Zimbabwe), and gold (England).

In the coming year, the program will be further developed to reflect the broad mandate of the new Precambrian Geology Section to upgrade and maintain, at the highest quality, the geological and mineral resource inventory of the Shield. To successfully achieve this goal, a balance must be kept between the various types of projects. Detailed mapping provides essential building blocks, but must be linked with both specific studies of mineral deposits and regional studies, in order that we can better establish the totality of the geological framework. The generation of new geoscience information must also be balanced with full use of existing information, which can in itself lead to better geological understanding; the Geology of Ontario, 1:250 000 scale compilation series maps, and use of PETROCH projects are examples of this effort. Likewise, if geological mapping, which is a research function, is to be done to the best possible level, other, more advanced research approaches must be an integral part of the Section's program, for example stable isotope studies and rare earth element determinations may help identify intrusions directly related to gold mineralization. We must also draw a balance between investigation of areas of current exploration interest and those which may hold potential for commodities in demand in the future, for example granitic-gneissic terrains for rare metals. We must be fully aware of advances in technology, for example remote sensing, and ensure that these are incorporated into all of our work, such that current projects are conducted to "state of the art" conditions.

002. A Reconnaissance Re-evaluation of a Number of Northwestern Greenstone Belts: Evidence for an Early Archean Sialic Crust

P.C. Thurston[1], A.L. Cortis[2], and K.M. Chivers[1]

[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Graduate Student, Department of Earth Sciences, University of Manitoba, Winnipeg, Manitoba.

INTRODUCTION

The "Geology of Ontario" project is designed to produce a state of the art geological map of Ontario at a scale of 1:1 000 000, plus tectonic, metallogenic, Pleistocene, and geophysical maps with a descriptive volume to celebrate the centennial of the Ontario Geological Survey in 1991. The first phase of this project is the revision of the geological map, entailing updating the geology of a number of greenstone belts in Northwestern Ontario.

Greenstone belts have been considered to represent volcanic cycles with a mafic or ultramafic base, passing upward to a felsic metavolcanic upper unit, forming one or more cycles, the whole commonly overlain by metasediments. Conventional wisdom suggested that this prevailing style was largely developed in deep water which became shallow as upper parts of the greenstone belts were deposited (Dimroth *et al.* 1982; Ayres and Thurston 1985). The upper parts of some of these sequences were deposited subaerially. In general, quartzites and sedimentary carbonates were considered to be scarce in the Archean sedimentary record (Armstrong 1960; Donaldson and Jackson 1965). Recently, supermature platform sequences have been discovered in several Superior Province greenstone belts (Wood *et al.* 1986; Thurston 1987; Donaldson and deKemp 1986).

These platformal sequences contain, from the base upward, quartz arenites with primary sedimentary structures produced by shallow water deposition, sedimentary carbonate±stromatolites, iron formation, and komatiitic or tholeiitic volcanic rocks. These platformal sequences tend to form the lower unit in a number of greenstone belts (Wood *et al.* 1986; Thurston 1987), are between 2980 and 3023 Ma in age, and are overlain by younger (2750 to 2700 Ma) greenstone sequences exhibiting normal mafic to felsic cyclicity (Thurston 1986).

The occurrence of these platform sequences is very important in understanding the tectonic development of the Superior Province and the Archean in general. They may represent one area underlain by platform sequences which have been spread apart by some sort of spreading mechanism. Therefore, several greenstone belts were selected for reconnaissance evaluation in the updating of the geological map of Ontario. The greenstone belts were selected on the basis of currency of geological mapping and the relationship to the previously known (Wood *et al.* 1986; deKemp 1987) platform sequences.

Selective mapping at a scale of 1:50 000 was carried out in several areas. The emphasis was upon establishing the presence and stratigraphic position of platformal sequences in several northwestern Ontario greenstone belts, and any necessary revisions of structure. Areas mapped in the Wabigoon Diapiric Axis Terrane (Figure 002.1) (Thurston and Davis 1985; Edwards and Sutcliffe 1980) included the Bo-Heaven Lake (Sage *et al.* 1974), Garden Lake (Milne 1964), Fletcher Lake (Sutcliffe 1984a) and Kawasheogama Lake (Trowell 1986) areas. In the Wabigoon Subprovince, platformal sequences have been recognized at Atikokan (Wilks and Nisbet 1985) and Lumby Lake (Wood *et al.* 1986). Mapping in Sachigo Subprovince was conducted at Stull Lake (Satterly 1938), Muskratdam Lake and Severn River (Ayres 1969b), Sandy Lake (Satterly 1939), Ponask Lake (Satterly 1938), and brief visits were made to sequences at Eyapamikama (Breaks *et al.* 1985) and Wunnummin Lakes (Stott and Janes 1985).

Detailed descriptions of modifications to the geology of the various belts is supplied here as some relationships are of use in exploration. As preliminary maps only are planned for some areas, detailed descriptions are supplied here.

WABIGOON DIAPIRIC AXIS TERRANE

BO-HEAVEN LAKE

The Bo-Heaven Lake greenstone belt was last mapped in detail by Milne (1964). The belt lies about 80 km north of Thunder Bay (Figure 002.1) and access is via lumber roads off Highway 527. The belt trends east to east-northeast and extends 64 km from Highway 527 to Saway Lake. Mapping was concentrated between Highway 527 and Whitten Lake (Figure 002.2). The sequence uniformly youngs south, based on pillow tops and primary structures in felsic pyroclastics. The lower mafic unit strikes northeast, is about 3000 m thick, and consists of pillowed tholeiitic mafic flows. This is overlain by about 600 m of pillowed to massive komatiitic flows with rounded small (average size <30 cm) pillows, and pyroxene spinifex-textured flows with some poorly developed serpentinized olivine-bearing cumulate zones. The upper part of the komatiite unit contains interbeds of silicate facies grunerite-bearing iron formation in places. The unit was mapped east of a northeast-trending shear zone, and its extension to the west is based upon interpretation of aeromagnetic data (ODM-GSC 1962). The komatiites are overlain by about 1200 m of tholeiitic flows succeeded by about 1000 m of intermediate pyroclastics in which reverse grading of pumice fragments suggests southerly tops. Vapor phase recrystallization of pumice fragments (cf. Thurston 1980) suggests subaerial deposition for this unit. Vapour phase recrystallization is the replacement of primary mineralogy during degassing of an ash-flow by late magmatic/hydrothermal mineralogy. This process is manifested by quartz after cristobalite replacing pumice fragments. Above the

intermediate pyroclastics is a unit of felsic pyroclastics with an apparent thickness of 5.5 km. The unit is felsic tuff to lapilli-tuff with quartz and feldspar phenocrysts. Phenocryst stratigraphy, pumice grading, and the vertical succession of primary structures suggest the unit is a stacked sequence of ash-flow depositional units, each hundreds of metres thick. The abrupt discontinuation of the unit west of Whistle Lake suggests that the unit represents a thick intracaldera facies. Vapor phase recrystallization and replacement of pumice fragments by quartz suggests subaerial deposition for the unit (cf. Francis and Howells 1973).

A minor unit of interflow conglomerate, a few metres thick, is a matrix-supported debris flow. It contains angular pebble to cobble clasts of scoriaceous to massive ultramafic and mafic metavolcanics.

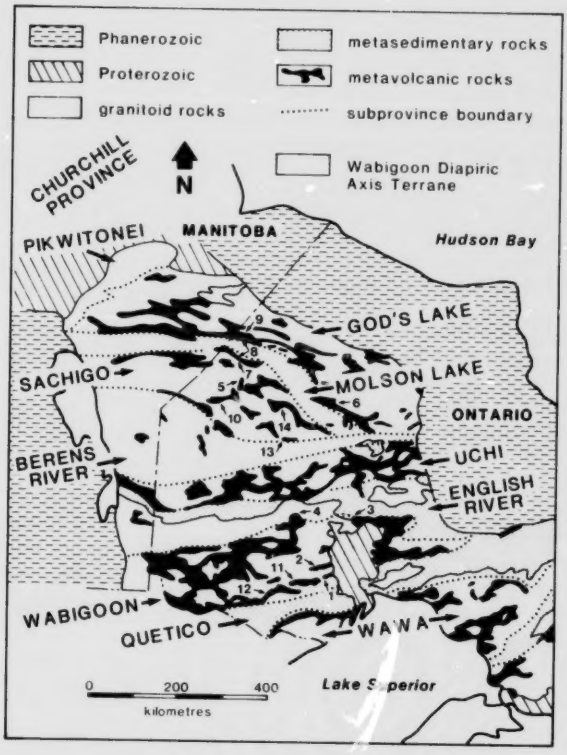

Figure 002.1. *Western part of the Superior Province. Subprovince and domain boundaries are shown by dotted lines; note the revisions to the extent of the Sachigo Subprovince. Greenstone belts examined for platform sequences or otherwise noted in the text are numbered on the Figure as:*

1) Bo-Heaven Lake, 2) Garden Lake, 3) Fletcher Lake, 4) Kashaweogama Lake, 5) Muskratdam Lake, 6) Wunnummin Lake, 7) Ponask Lake, 8) Transect of granitic area, 9) Stull Lake, 10) Sandy Lake, 11) Lumby Lake, 12) Steep Rock Lake, 13) Horseshoe Lake, 14) Eyapamikama Lake.

Metasediments along the northern margin of the belt, in the vicinity of the pyrite occurrence west of West Lacasse Lake (Sage *et al.* 1974) consist of a 10 to 15 m wide unit of conglomerate, arkose to wacke, and sulphide facies iron formation. The conglomerate is matrix-supported, with pebbles and cobbles of mafic metavolcanics, intermediate metavolcanics, tonalite, vein quartz, and gneissic clasts overprinted by a second foliation.

Structure

The sequence is a south-facing homocline trending east-northeast. Structural relationships described above suggest that the supracrustal rocks were deformed prior to intrusion of the late granitoid rocks along the northern margin of the greenstone belt.

The nature of the northern granite-greenstone contact is variable. Along Highway 527, the contact is sheared dextrally and trends west with sheared intermediate pyroclastics in sharp contact with slightly deformed megacrystic hornblende–K-feldspar quartz monzonite. To the west of Chisamore Lake, the contact is intrusive with massive coarse-grained biotite tonalite intruding and brecciating sheared amphibolite which has a strong internal schistosity and mineral lineation.

Minor folds within the supracrustals have axial planes striking approximately 330°. Mineral lineations trend north to northeast and plunge at about 70°. Fold interference structures suggest that the area exhibits two episodes of folding, which are both overprinted by the above mineral lineations. The supracrustal belt is cut by a northeast-trending dextral shear zone which offsets the stratigraphy unit about 1200 m (Figure 002.2).

Evidence for Shallow Water Depositional Environment

The following features of the Heaven Lake greenstone belt suggest a shallow water depositional environment:

1. less than 5 percent 2 to 3 mm slightly stretched vesicles in massive stringbeef spinifex textured komatiitic flows with a well developed rubbly flow top zone; vesicles are rarely reported in spinifex textured komatiites
2. pillowed tholeiitic flows suggesting shallow water volcanism (cf. Jones 1969)

The felsic metavolcanic units show vapor phase recrystallization textures demonstrating that the units were deposited subaerially. These relationships suggest that the mafic/ultramafic volcanic environment was shallow water and that the belt became subaerial before felsic volcanism took place.

The quartz arenite-iron formation-komatiite association was not observed; however, more detailed mapping in the vicinity of the tholeiite-intermediate contact is warranted. Komatiites and platform sequences, where noted within the Wabigoon Subprovince, are restricted to sequences >2.9 Ga as follows:

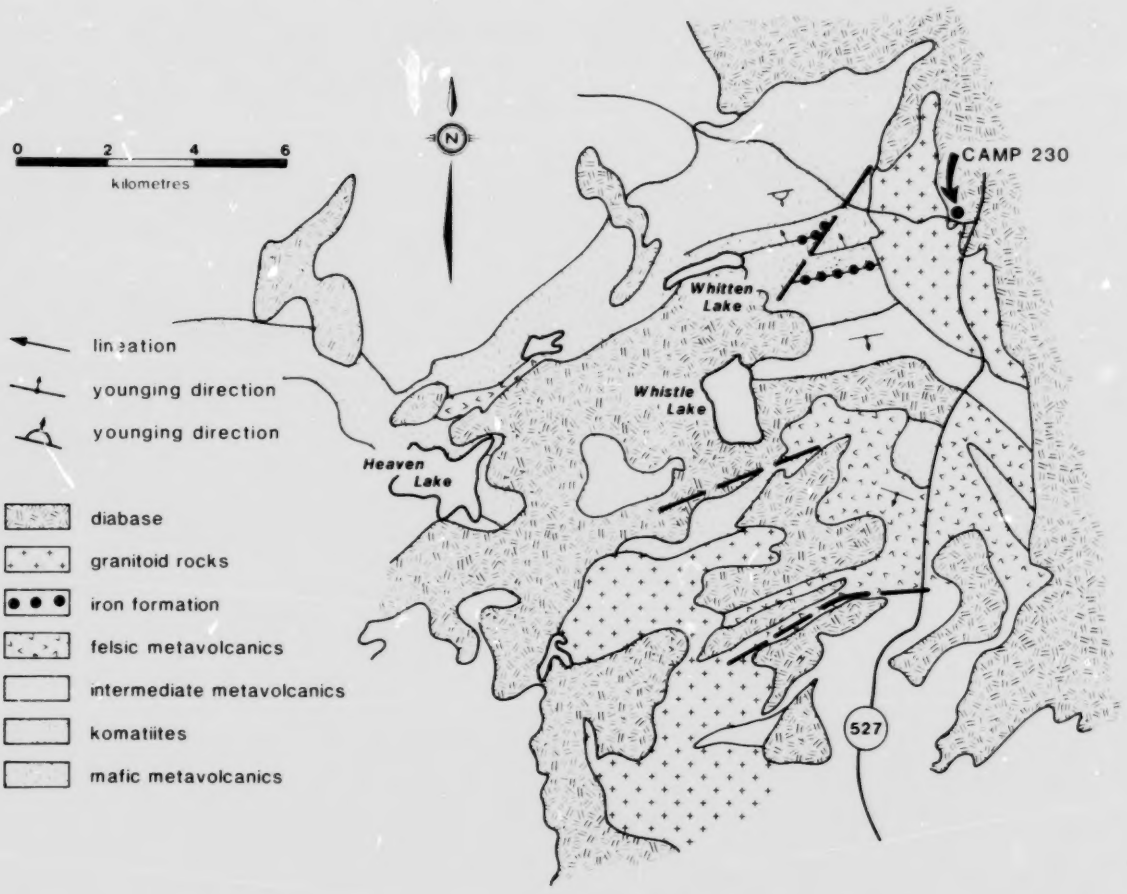

Figure 002.2. *Simplified geological map of the eastern part of the Bo-Heaven Lake greenstone belt. The map emphasizes the units not appearing on the compilation of Sage et al.* 1974.

Location	U-Pb Zircon Ages
Ash rock Atikokan Platform sequence present (Wood *et al.* 1986	3004 Ma on overlying rhyolite (personal communication, D. Davis, 1987)
basaltic komatiites Lumby Lake Platform sequence present (Wood *et al.* 1986)	2999 Ma on rhyolite (Davis and Jackson 1985)
high Mg basalts (Jutten Series) Platform sequence present (personal communication, R. Sutcliffe, 1987)	>2703 Ma (Trowell 1986)
peridotitic komatiite Fletcher L. Platform environment present (this work)	cut by 3075 Ma granitoids (Davis *et al.* 1987)

Therefore, it is suggested that the Heaven Lake greenstone belt may be >2.7 Ga and may contain early platformal sequences.

GARDEN LAKE

Location and Access

The Garden Lake-Kearns Lake greenstone belt is located approximately 160 km north-northwest of Thunder Bay and is one of the many greenstone belts within the Wabigoon Diapiric Axis (Figure 002.1). Access to the area is by lumber roads off Highway 527 with minor portages of less than 0.4 km giving access to the major lakes.

Previous Work

Previous work in the area was performed mainly by Milne (1964). Readers are referred to this work for further references.

Tholeiites

Flows are variably massive, vesiculated, and pillowed with an assemblage of hornblende-plagioclase or

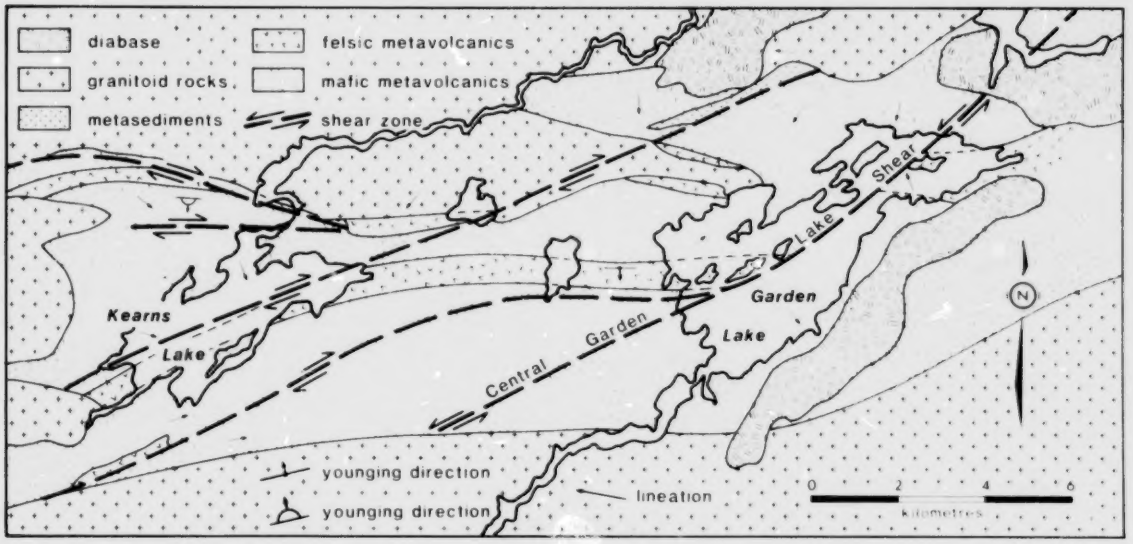

Figure 002.3. *Simplified geological map of the Garden Lake greenstone belt. The shear zones shown have not been previously mapped and represent gold exploration targets.*

chlorite-actinolite-plagioclase±epidote. On the northeastern corner of Kearns Lake (Figure 002.3) rubbly nonpillowed subaerial, massive, 30 cm to 1.5 m thick, andesitic flows are epidotized and contain 20 to 30 percent carbonate filled vesicles with 30 to 50 cm thick rubbly flow top breccias. To the south of Kearns Lake the sequence observed is north younging, interlayered mafic and intermediate metavolcanics ranging upward from pillowed and massive flows with minor interflow felsic metavolcanics, banded iron formation, and pelitic metasediments, to massive, vesiculated flows with rubbly tops followed by a greater than 300 m thick sequence of thickly bedded andesitic tuff, lapilli-tuff, and tuff breccia with abundant inversely graded chloritic pumice.

Felsic Metavolcanics

Felsic metavolcanics were observed in several localities throughout the belt. On the eastern end of Garden Lake, 15 to 20 cm thick beds of tuff and lapilli-tuff of andesitic to dacitic composition contain 1 to 2 percent siliceous clasts and various proportions of pumice. To the north of Garden Lake, very fine grained plagioclase-quartz phyric tuff contains abundant chloritized pumice and youngs south. On the western end of Garden Lake, metre-scale lapilli-tuff beds with 40 percent dacitic lapilli are capped by 10 cm thick tuff beds. Northeast of Kearns Lake, a thick south younging felsic volcanic sequence consists of a 3 m thick heterolithic debris flow, a 1.5 m thick feldspar-phyric ash flow with 5 percent chloritic pumice lapilli, a 15 cm thick base surge unit with crossbeds and dacitic tops, a 1 m thick unit of dacitic tuff with a 10 cm thick crossbedded base surge deposits, a 1 m thick ash flow, and a 2 to 2.5 m thick unit of felsic flows containing flow banded fragments. The presence of both flows and ash flows suggests a location proximal to a vent (Williams and McBirney 1979). On the western end of Kearns Lake, dacitic tuffs contain 15 percent plagioclase phenocrysts and are interpreted as poorly graded ash flows. Silicification of pumice and welding textures in the andesites suggest a subaerial deposition. Minor felsic volcanic rocks with 1 to 2 m thick depositional units of tuff and lapilli-tuff occur to the south of Kearns Lake, interlayered with mafic and intermediate volcanic rocks. These are mylonitized, chloritized, and silicified where found within the shear zone forming the southern boundary of the greenstone belt.

Metasediments

Two separate metasedimentary units were recognized; a distinctive narrow (<100 m) clastic metasedimentary band within the mafic metavolcanics to the north of Garden Lake, here termed the Northern Metasedimentary unit, and centrally located clastic and chemical sediments related to the large felsic metavolcanic unit (Figure 002.2). The Northern Metasedimentary unit consists of garnet-bearing semipelites and polymictic pelitic matrix-supported cobble to pebble conglomerate with angular to subrounded clasts. Studies reveal a modal composition of 59% matrix, 27% mafic volcanic rocks, 10% felsic volcanic rocks, and 2% vein quartz clasts. Quartz arenite to quartz wacke clasts within the conglomerate comprise <1%, and are small, angular and <5 cm in diameter. These contain 85 to 95% well rounded fine to medium sand sized quartz grains in a contact framework. The Northern Metasedimentary unit pinches out laterally westward and is bounded by a granite pluton to the east and an oblique slip dextral shear to the south. The centrally located metasediments are of both clastic and chemogenic nature. The clastic metasediments on Garden Lake consist of south-younging proximal turbidites a few tens of metres thick, with dominantly ABDE sequences (Walker 1979) and abundant medium-bedded arkoses with 44% chlorite, 26% plagioclase,

21% quartz, and 9% fragments (mafic lithic grains). On Kearns Lake, conglomerates are intimately associated with thin-bedded graphitic magnetite-bearing cherts and minor Fe-carbonates. The conglomerate is a thickly bedded, polymict, matrix-supported unit containing 56% chlorite-rich wacke to silty mudstone matrix, 19% felsic volcanic clasts, 13% vein quartz clasts, 11% mafic volcanic clasts, and 1% tonalitic to trondhjemitic granitoid clasts.

Silicification and pyritization of the shear zone south of Kearns Lake was observed in recent trenching. In general, the Kowbel-Kearns shear zone is a good exploration target for gold.

Granitoid Rocks

To the north of the belt, diorite to tonalite gneisses with very minor flaser banded quartzofeldspathic units plunge shallowly to the southwest. This is cut by myriad northeast-trending biotite tonalite dikes. To the south of the belt, coarse-grained mylonitized tonalites exhibit *lit-par-lit* injection into sheared amphibolites.

Structure

The dominant structural units in the belt, from northeast to southwest, are as follows:

In the northeast, southwest-facing tholeiites and the Northern Sedimentary unit contain steeply plunging southeast-trending lineations. These are separated from southwest-facing tholeiites and felsic metavolcanics by a large dextral shear zone extending through Kowbel (Gar) Lake to Kearns Lake.

These southwest-facing tholeiites are in turn rotated to the southwest by a large sinistral shear zone which strikes down the centre of Garden Lake where it offsets the felsic-sedimentary unit and then passes probably to the granite-greenstone contact. We term this the Central Garden Lake shear zone. To the south of Kearns Lake, a prominent dextral shear zone passing through Agar to Garden Lake is also offset by the Central Garden Lake shear zone. Numerous splays of this shear zone pass through all supracrustal rocks and along the granite greenstone boundary, causing intense deformation and mylonitization.

Evidence for Shallow Water Depositional Environment

Subaerial andesitic flows and welded ignimbritic pyroclastics observed on Kearns Lake are all indicative of a shallow water to subaerial setting for deposition of the supracrustal rocks. Similarly, arkosic sediments and quartz arenite clasts in conglomerate in the Garden Lake area suggest a proximal shallow water setting. This is also suggested by fine-scale laminated banded iron formation which is seen on Garden Lake (cf. Trendall 1983). The Garden Lake supracrustal rocks may be greater than 2.9 Ga in that all U/Pb dated quartz arenite sequences in the Superior Province are >2.9 Ga (Wood *et al.* 1986).

FLETCHER LAKE

The Fletcher Lake area is 30 km northwest of Armstrong and forms part of the Caribou Lake-Pikitigushi River greenstone belt of the Wabigoon Subprovince. The belt has been previously mapped by Sutcliffe (1984a) and Gussow (1942). The belt was examined in this project because it lies within the Wabigoon Diapiric Axis Terrane (Edwards and Sutcliffe 1980) and the occurrence of komatiites (Sutcliffe 1984a) suggests the existence of platformal sequences.

The area north of the Caribou Lake Fault along the western shore of Caribou Lake was examined because R.H. Sutcliffe (Geologist, Ontario Geological Survey, Toronto, personal communication, 1987) suggested that fault blocks with iron formation in contact with granitoid rocks may represent allochthonous blocks in fault contact with the granitoid rocks. Indeed, blocks about 400 m wide by 3 to 5 km long, trending northeast parallel to the granite greenstone contact on Map P.2409 (Sutcliffe 1984b), have distinct structures. The principal evidence for this is variation in trend and plunge of lineation from a northeast trend, plunging 15° to 35° in the granitoids, to a block of tholeiites immediately east of the granite-greenstone contact with lineation trending southeast to southwest, plunging 22° to 55°. Limited mapping of shoreline exposures on Caribou Lake suggests that tholeiites on Map P.2409 (Sutcliffe 1984b) may include a unit of komatiites of limited extent close to the granite-greenstone contact at Longitude 89°00′00″W to 89°01′30″W and Latitude 50°30′N to 50°31′N. Within the komatiitic unit, metre-scale blocks of banded or bedded felsic metavolcanics occur.

Campbell Lake in the northern part of the map area was examined. The sequence consists of east-trending felsic pyroclastics with steep southerly dips. The rocks are pink to green sericitic felsic lapilli-tuff in poorly bedded units 60 cm to 2 m thick with reverse pumice grading, suggesting tops south. A similar unit, 2 km south of Campbell Lake, reveals tops north, suggesting, based on mineral lineations, a major easterly plunging syncline centred upon Campbell Lake. The cherty iron formation south of Campbell Lake was checked for possible quartz arenite beds; none were observed.

The felsic subvolcanic unit at Howie Lake has been reinterpreted by the authors as a sequence of north-facing felsic ash flows based on grading of pumiceous fragments. Silicification of pumice fragments suggests that the unit was deposited subaerially (cf. Thurston 1980).

The Caribou Lake-Pikitigushi River greenstone belt is cut by biotite tonalite gneiss which is in turn cut by abundant amphibolite dikes. The tonalite has a $^{207}Pb/^{206}Pb$ age of 3075 Ma; therefore, the greenstone belt is >3075 Ma (Davis *et al.*, in press). The oxide and silicate iron formation suggests shallow water deposition (cf. Trendall 1983) as does the subaerial nature of the felsic metavolcanics. Further mapping and geochronology is needed to establish whether the sequence is platformal.

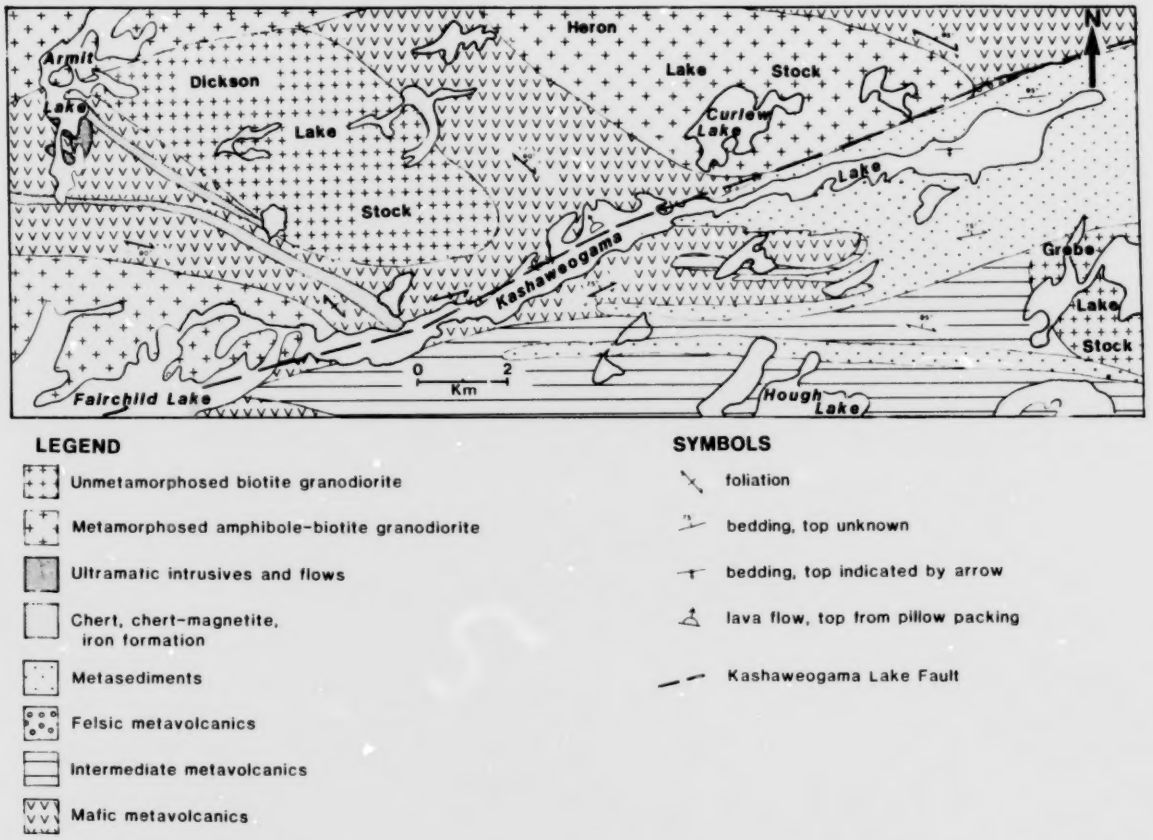

Figure 002.4. *Simplified geological map of the Kashaweogama Lake portion of the Savant Lake greenstone belt (after Trowell 1986).*

KASHAWEOGAMA LAKE

Location and Access

Kashaweogama Lake is located west of Highway 599, 25 km north of the Town of Savant Lake. A 2 km long forest access road provides access to the Kashaweogama-Fairchild Lakes system. Armit Lake is accessible by float-equipped aircraft.

General Geology

The rocks of the Kashaweogama Lake area are part of the Savant Lake volcano-sedimentary belt (Trowell 1986). The basal unit of this belt consists of mainly mafic metavolcanics of the Jutten Volcanic group which has been intruded by both the Dickson and Heron Lake Stocks. It is unconformably overlain by the metasediments of the Savant Narrows formation.

The present survey confirms the work completed and described in detail by Trowell (1986) (Figure 002.1). The main lithological units found within the supracrustal rocks of the map area (Figure 002.4) are as follows:

1. Northward facing, dominantly fine-grained, massive and pillowed mafic metavolcanics comprise the Jutten Volcanic group. Autoclastic/hyaloclastic breccia, feldspar porphyritic flows, and variolitic flows were also noted in a few localities.
2. Ultramafic intrusions, found exclusively in the Armit Lake area, range from pyroxenite to peridotite in composition. A few laterally discontinuous ultramafic flows were observed in this vicinity. These intrusions and flows are the stratigraphically lowest portion of the Jutten Volcanic group.
3. Two laterally continuous units of intercalated chert and grunerite-bearing chert-magnetite iron formation were found within the Jutten Volcanic group (Figure 002.4). In some localities these chert units are strongly deformed, while in others folding was poorly developed and brittle shearing was dominant.
4. Southward-facing polymictic conglomerate and associated fine-grained metasediments comprise the Savant Narrows Formation. The conglomerate varies from clast- to matrix-supported and is primarily composed of coarse-grained, subrounded to rounded granitoid clasts. Other clasts found within the conglomerate are composed of either chert, quartz-feldspar porphyry, or fine-grained mafic metavolcanics. The contact between the conglomerate and the underlying Jutten Volcanic

group is believed to represent a major unconformity in the Savant Lake area (Skinner 1969; Bond 1977; Shegelski and Bell 1976).

A small, discontinuous, previously unreported unit of felsic pyroclastics was found adjacent to, and east of, the Heron Lake Stock (Figure 002.4). These felsic pyroclastics are primarily tuff and lapilli-tuff composed of quartz and plagioclase phenocrysts in a fine-grained quartz, plagioclase and chlorite-rich matrix.

Structural Geology

The regional structural geology of the Kashaweogama Lake area has been described by Trowell (1986).

The rocks of the Jutten Volcanic group within the map area generally strike northwestward and dip 80° to 90° to the northeast. Foliation and bedding in the overlying metasediments of the Savant Narrows formation are approximately parallel, striking east-northeastward and dipping 70° to 85° north. Within both the Jutten group and the Savant Narrows formation, foliation near the Kashaweogama Lake fault has been rotated parallel to the fault.

Top determinations were made on the basis of the packing of pillowed flows and normal grading of clasts. Within the map area, the younging direction of the Jutten Volcanic group is northward, while the metasediments of the Savant Narrows formation top to the south.

The major fold within the map area, as determined by Trowell (1986) is found north of Kashaweogama Lake. There the Jutten Volcanic group has been folded about an east-trending, steeply east-plunging synclinal axis, the southern limb of which has been interrupted by the Heron and Dickson Lakes Stocks (Trowell 1986).

The Kashaweogama Lake fault is a regional fault transecting the map area, trending approximately east-northeast, and has caused intense shearing of all units adjacent to it. Trowell (1986) postulates that brittle deformation along the Kashaweogama Lake fault resulted from reactivation of earlier marginal faults within the area.

The supracrustal rocks of the Jutten Volcanic group are cut by the Heron Lake pluton which is 2675 Ma in age (Davis *et al.*, in press). Conglomerate clasts from an overlying unit yield a U/Pb zircon age of 2703.7±1.2 Ma, a maximum age for the conglomerate (Davis *et al.*, in press). Hence, the Jutten group is older.

Paleoenvironmental interpretation of this part of the Jutten sequence is difficult; basaltic rocks are not particularly vesicular, but the chert and chert magnetite information may represent shallow water deposition (cf. Trendall 1983).

Arenaceous metasediments have been reported by Trowell (1986) in the Jutten Volcanic group east of the present study area. These metasediments at the northern end of Savant Lake will be investigated in a subsequent phase of the project.

SACHIGO SUBPROVINCE

MUSKRATDAM LAKE

Previous mapping includes the work of Ayres (1969b) and reconnaissance work in the early 20th century.

Ayres (1969b) established a stratigraphy for the belt as shown in Figure 002.5.

The general structural-stratigraphic interpretation is confirmed by the present work.

Significant new findings are shown on Figure 002.6 as follows:

1. Within the lower sequence, the basal basalts include 200 m of komatiitic pillowed flows immediately north of Nekence Lake.
2. The overlying iron formation unit includes quartz arenite beds with medium-grained subangular recrystallized quartz comprising 95 percent of the sediment. These are gradually succeeded by more aluminous cummingtonite(?)-bearing clastic metasediments. The quartz arenite units are cut by quartz-tourmaline veins, and are traced laterally from the Windigo to the Fox River. Also seen was a 1 m wide conglomeratic bed with a quartz arenite matrix that includes, among other clasts, rare sericitic felsic metavolcanic and fuchsitic chert clasts. This is similar to conglomerate within the quartz arenite sequence seen on east Sandy Lake.
3. This is overlain by bedded, graded, rhyolitic to dacitic tuff to tuff breccia with interbedded conglomerates containing ultramafic and quartz arenite clasts. The unit represents subaqueous deposition of air-fall volcanism based on the grading and presence of water-laid conglomerates.
4. The marble unit at the top of the lower unit consists of thin (15 cm) marble beds in diopside-calcite-biotite-tremolite±quartz, plagioclase calc-silicate beds.
5. Within the upper volcano-sedimentary cycle, the upper part of the mafic unit is pillowed amygdular andesitic flows.
6. The metasediments of the upper sequence consist of reworked andesitic proximal tuff to tuff breccia with good bedding, grading, and sorting overlain by graded siltstones, arenites, and conglomerates. Conglomerates in the Fox Bay area of the upper sequence have modal proportions as follows:

matrix	41-61 %
gabbro	0-26 %
mafic metavolcanics	10-36 %
felsic metavolcanics	0- 3 %
sedimentary rocks	0- 6 %
chert	5-16 %
iron formation	0- 5 %
quartz arenite	0- 2 %
vein quartz	0- 2 %

West of Sandhill Crane Island, the conglomerates of the upper sequence contain almost exclusively sedimentary clasts. Quartz arenite clasts occur

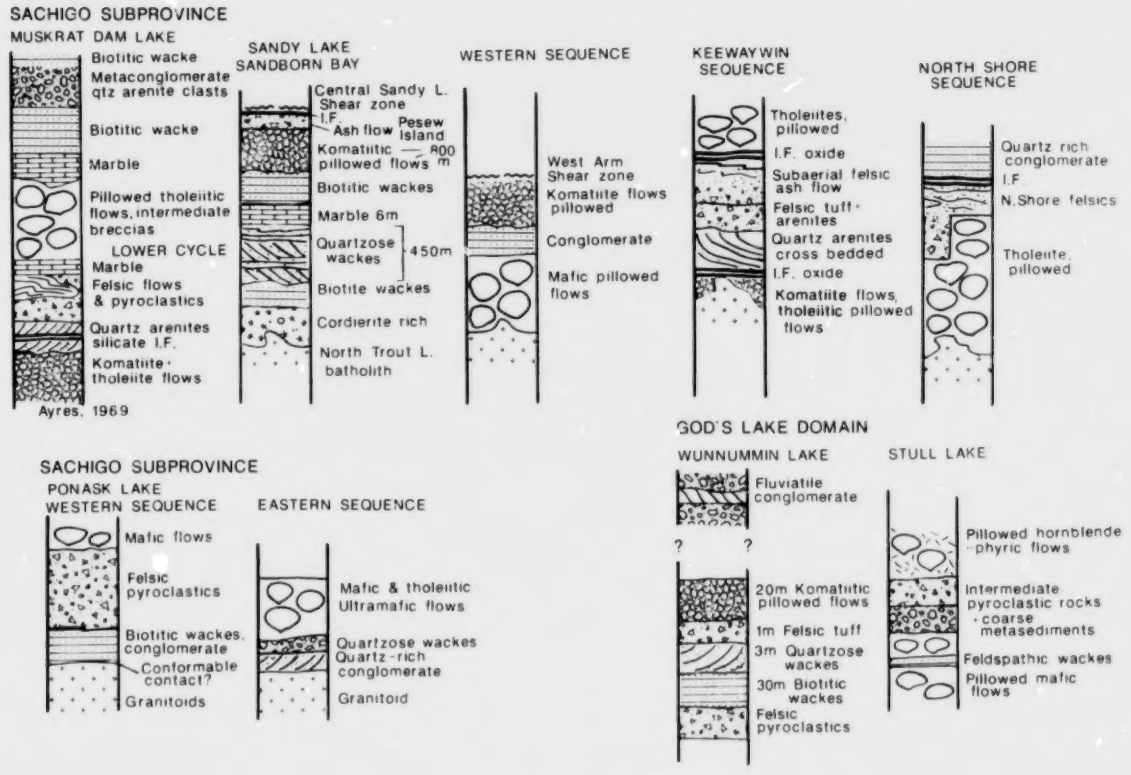

Figure 002.5. *Generalized sections of the Sachigo Subprovince greenstone belts.*

sporadically reaching a maximum of 15% in a 3 m thick bed.

The presence of quartz-arenite clasts cut by quartz veins west of Sandhill Crane Island suggest erosion of the earlier quartz arenite-bearing sequence and the possible occurrence of an early alteration or orogenic event. Wackes interbedded with the conglomerates occur as 5 cm to 2 m beds of coarse subangular sands containing up to 25 to 30% subangular to rounded clastic quartz and 10% lithic clasts. Most conglomerates have an arenaceous matrix. One conglomerate unit consists of 30 cm to 2 m thick graded beds with 61% matrix, and clasts as follows: 19% mafic metavolcanics, 9% vein quartz, 3% felsic metavolcanics, 1% intermediate metavolcanics, 5% chert, and 2% quartz arenites. The matrix is calcitic carbonate and a 1 to 1.5 m thick bedded, stromatolite-bearing carbonate unit overlies the conglomerate. This conglomerate contains an argillite clast with polygonal mudcracks. Again, shallow water deposition is suggested.

7. Along the Severn River, an east-trending carbonatized shear zone cuts the felsic metavolcanics near the contact with the mafic metavolcanics. Centimetre scale iron carbonate pods were observed in the shear zone which has sinistral offset.
8. At least some of the former gabbros (Ayres 1969b) on the Severn River are komatiitic flows based on the presence of rubbly flow top, spinifex texture, and a knobby weathering cumulate zone.

Evidence for Shallow Water Depositional Environment

The presence of quartz arenite, sedimentary carbonate, oxide and silicate iron formation in the lower cycle suggests that this unit is a platform sequence similar to those previously described by Wood *et al.* (1986) and deKemp (1987). The stromatolitic carbonate toward the top of the upper volcano-sedimentary cycle also represents shallow water deposition because stromatolites are restricted to the photic zone (Playford and Cockbain 1976).

WUNNUMMIN LAKE

Wunnummin Lake lies 170 km north of Pickle Lake. Access is via float-equipped aircraft. The metavolcanic-metasedimentary belt was mapped by Prest (1942) and was included in regional reconnaissance by Thurston *et al.* (1979). The structural geology of the area was examined by Stott and Janes (1985) who discovered, within the 7 km wide belt, an 8 km long and 20 m wide unit of tremolitic ultramafic pillowed flows. The presence of ultramafic flows suggested the presence of a platform sequence, there-

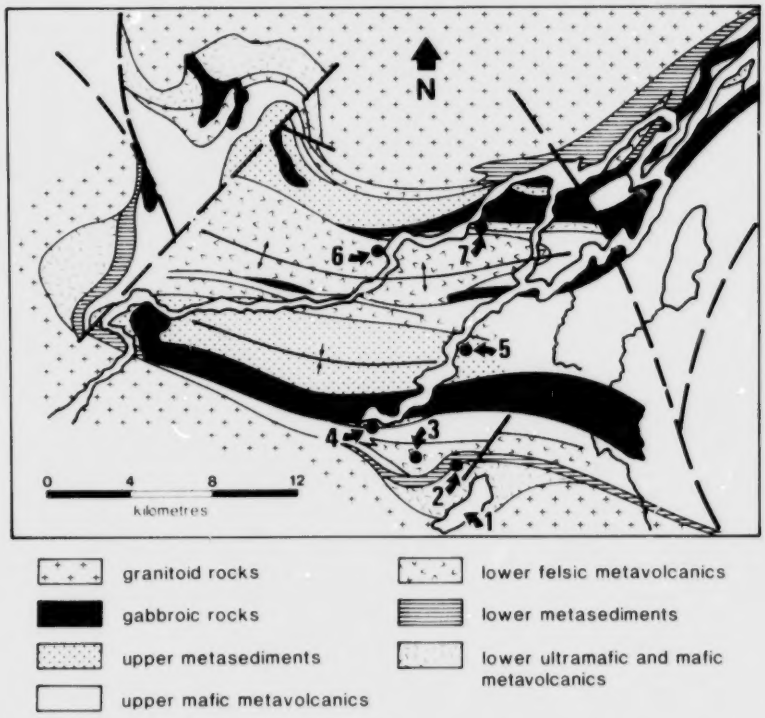

Figure 002.6. *Sketch map of the Maskratdam Lake greenstone belt (after Ayres 1969) with locations of new or critical relationships described in the text.*

1) komatiitic omatiitic flows in the lower basalt unit
2) quartz arenites in the lower cycle iron formation unit
3) lower cycle metasediment-metavolcanic unit
4) marble unit in the upper point of the lower volcano-sedimentary cycle
5) upper volcanic cycle andesitic flows
6) conglomerates of the upper cycle. Number locates stromatolite-bearing carbonate unit
7) carbonatized shear zone
8) komatiitic flows

fore this succession was examined. An approximate stratigraphic column is shown in Figure 002.5.

20 m	komatiitic pillowed flows and pillow breccia
1 m	felsic tuff, very fine grained, possibly bedded
3 m	quartzose wackes with 60 to 80% poorly rounded 5 mm quartz, 10 to 15% rounded altered feldspar, 5 to 25% wacke matrix with fine-grained quartz, plagioclase, and biotite
30 m	fine-grained wacke beds with uncommon argillaceous tops
2500 m	pillowed mafic flows

The sequence above the mafic flows is lithologically similar to platform sequences elsewhere in the Sachigo Subprovince (Breaks *et al.* 1985, 1986; deKemp 1987), therefore it is suggested that the above stratigraphic package represents a platform sequence.

Geochronological samples were taken of the felsic metavolcanic and quartzose metasediment units.

PONASK LAKE

Location and Access

The Sachigo-Ponask Lake metavolcanic-metasedimentary belt is located 320 km north of Red Lake and access is via float-equipped aircraft. The area mapped is the central portion of the greenstone belt which extends from Sachigo Lake northwestward to Pierce Lake near the Manitoba Border (Bennett and Riley 1969). Centrally located on Ponask Lake, the Sachigo Lake Indian Reserve No. 2 was mapped by permission of Jack Barkman and the Sachigo Lake Band Council. Barkman also provided guiding assistance on the lake.

Previous Work

Reconnaissance mapping was performed by Satterly (1938) and by Bennett and Riley (1969). More recently, Lake Ponask Gold Corporation conducted extensive diamond drilling in the Winter of 1986, concentrating on the central and western portions of the lake.

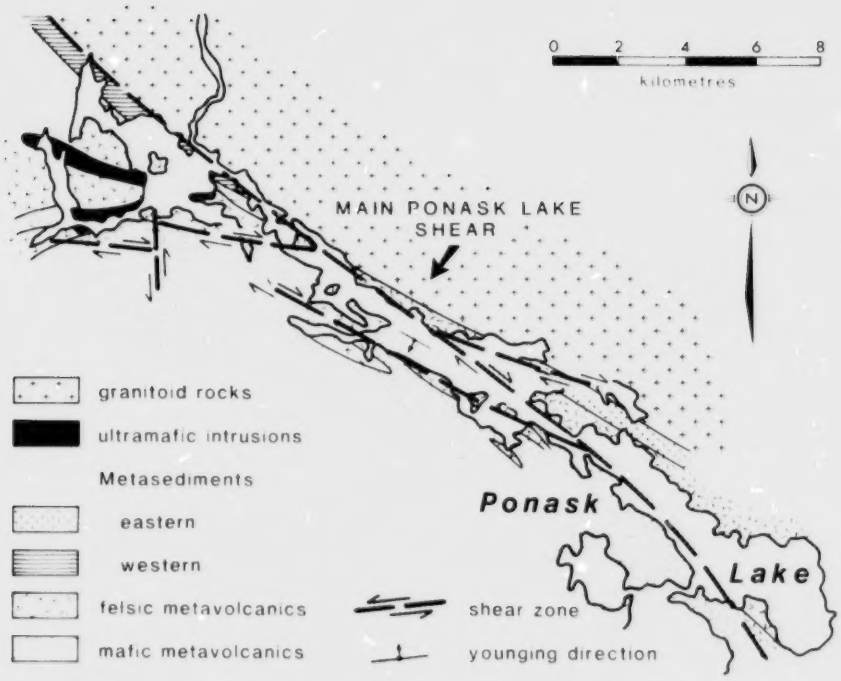

Figure 002.7. *Sketch map of the central part of the Sachigo-Pearce Lake greenstone belt.*

Metavolcanics

Within the Ponask Lake greenstone belt, metavolcanics of ultramafic to felsic composition were encountered. These metavolcanic rocks comprise over 90 percent of the belt.

The belt is divided into eastern and western supracrustal units on the basis of distinctive metasediments in each unit. The eastern and western supracrustal units are separated by an oblique shear zone, the Ponask Lake Shear Zone (Figure 002.7). The south-younging eastern supracrustal rocks are of dominantly ultramafic to intermediate composition with minor intercalated felsic metavolcanics whilst the western supracrustal rocks are dominantly of felsic to intermediate composition with only minor mafic metavolcanics.

Ultramafic Association

Within the eastern supracrustal rocks, ultramafics are spatially related to the main Ponask Lake Shear. All localities exhibit a very fine grained, highly schistose actinolite-chlorite-talc assemblage with no primary textures. Based on their intimate association with pillowed plagioclase-phyric, mafic to intermediate pillowed flows, they are suggested to be of volcanic origin. Within the western supracrustal rocks, the massive peridotitic sills and a layered ultramafic to mafic intrusion are located within the western part of Ponask Lake. The intrusions are generally coarse-grained talc-actinolite-chlorite rocks, although abandoned drill core revealed asbestiform serpentine and talc-magnetite at depth.

Mafic to Intermediate Association

Mafic to intermediate metavolcanics are variably sheared to strongly foliated massive, pillowed, and vesicular with a hornblende-chlorite-plagioclase assemblage. Intermediate metavolcanics are usually plagioclase-phyric with phenocrysts up to 1 cm long. Tuff to lapilli-tuffs bedded on a centimetre scale were found in the southwestern bay on Ponask Lake and on small islands immediately west of the Indian Reserve, interlayered with pillowed intermediate metavolcanics. Pumice grading here suggests tops to the south. On the southeastern shore of Ponask Lake, near the channel to Anchicum Bay, gradation of stretched pillowed mafic metavolcanics into a flow top breccia zone also suggests south facing for the eastern supracrustal rocks.

Felsic to Intermediate Association

Felsic to intermediate metavolcanics are aphanitic to slightly plagioclase-phyric, with only minor <1 mm phenocrystic quartz. The common mineral assemblage is plagioclase-quartz-chlorite-muscovite. On the southern shore of central Ponask Lake, thick bedded plagioclase-phyric tuff to lapilli-tuff ash flows contain dominantly plagioclase phenocrysts comprising 20 percent of the rock. Plagioclase phenocrysts are up to 1 cm and euhedral whilst quartz phenocrysts are generally rounded and <2 mm. Inverse grading of chloritized pumice indicates younging to the south. A sample of this unit was obtained for geochronology. Immediately south of this unit, a large concordant felsic synvolcanic sill contains up to 50 percent coarse, angular quartz up to 4 mm in diameter, and is

hosted within mafic to intermediate metavolcanics. A geochronological sample was also taken from this unit.

Metasediments

As with the metavolcanics, the metasediments within the western and eastern supracrustal units are of differing types. The eastern supracrustal metasediments comprise a sequence of sheared quartzose wackes and conglomerate. The quartzose wackes are intensely sheared with all primary fabric overprinted. Remnant detrital grains of 2% quartz and 8% plagioclase are found within a very fine grained quartz-plagioclase-muscovite-biotite matrix. Metaconglomerate, exposed on a small lake just north of Ponask Lake, is a very quartz-rich (80 to 90%), immature, matrix-supported granule to pebble polymictic conglomerate. The matrix is quartz+biotite+chlorite± plagioclase. Modal analysis reveals 36% matrix, 5% fuchsitic clasts, 3% quartz arenite clasts, 18% mafic volcanic clasts, 14% felsic volcanic clasts, 16% chert clasts, and 8% banded iron formation clasts. The quartz arenite clasts within the conglomerate are mineralogically mature, but lack the textural maturity of quartz arenites seen in the Muskratdam, Sandy, and Eyapamikama Lake platformal sequences. Of note is the strong resemblance of this conglomerate to lower unit conglomerates at Sandborn Bay, Sandy Lake greenstone belt, and in the lower sedimentary unit in the Muskratdam Lake belt. This conglomerate was sampled for geochronological studies.

The western sedimentary group is comprised mostly of biotite-hornblende wackes which are strongly boudinaged and drag folded, interlayered with mafic to intermediate volcanic rocks. The unit is laterally continuous from Pierce Lake (Satterly 1938) to the north-central part of Ponask Lake. Sheared quartzose wackes in contact with mylonitized trondhjemite were observed just north of the westernmost bay of Ponask Lake. Lack of intrusive breccia, granitoid dikes in the sedimentary rocks, and volcanic and sedimentary xenoliths within the granitoids near the contact, suggest that the contact may be a sheared unconformity (cf. Clark *et al.* 1981). Conglomerates associated with the western supracrustal rocks are distinct from those in the eastern supracrustal group. The western conglomerates are deformed oligomict to polymict, granule to pebble, matrix-supported conglomerate, with a hornblende-biotite siltstone matrix and rare detrital quartz and plagioclase. Modal analysis indicates 20 to 60% matrix, 20 to 60% granitoid clasts, 3 to 5% mafic metavolcanic clasts, 5 to 10% angular chert fragments, and <1% vein quartz clasts. The granitoid clasts are identical to the tonalites and trondhjemites seen immediately to the north of the unit and are possibly derived there, from further evidence for the unconformity hypothesis. Localized tops are to the north, but due to intense mesoscopic folding of units younging directions cannot be determined unequivocally.

Granitoid Rocks

Along the northern contact of the belt, mylonitized trondhjemite and strongly foliated quartz and quartz-diorites are in contact with the western and eastern supracrustal rocks respectively. A gradation from mylonitized to massive trondhjemite was observed over approximately 2.5 km along the Ponask River. Where undeformed, away from the belt, these granitic rocks are cut by a myriad of pegmatite dikes. All granitic rocks contain hydrous phases except within the western mylonitized zone.

Structure

The supracrustal rocks and north-bounding batholiths are all strongly deformed and have been subjected to at least two deformation events. D_1 is the dominant deformational event and comprises intensely developed S and L fabric and folds related to dextral shearing along the main Ponask Lake shear zone which strikes east-southeast from the granite-greenstone contact near the outlet of the Ponask River to Anchicum Bay. This shear separates the two supracrustal groups with apparent offset and possibly repetition of stratigraphy caused by related splay faults. Lineations generally trend parallel to belt contacts with abrupt changes in plunge across the shear zones. The D_2 event has only affected the central part of the belt imposing a mild north-northeast-trending and steeply plunging crenulation on D_1 schistosity.

Evidence for Shallow Water Depositional Environment

Within the western supracrustal rocks, the presence of a possible erosional granite-greenstone contact and the marked similarity of dominant granitoid clasts in the conglomerate is suggestive of deposition upon a pre-existing sialic basement. Similarly, a shallow water platformal setting is indicated by quartz arenite clasts in the eastern supracrustal group conglomerate, and by the similarity of this unit, both lithologically and stratigraphically, to other established platformal sequences within the Sachigo Subprovince. The presence of the quartz arenite clast and a possible prevolcanic sialic basement suggest by analogy (deKemp 1987; Wilks and Nisbet 1985) a great age (>3 Ga) for at least the eastern supracrustal unit.

TRANSECT OF GRANITIC TERRANE BETWEEN SACHIGO–PONASK, AND STULL LAKE GREENSTONE BELTS

The granitoids separating these greenstone belts were examined by traverses along the Ponask River north from Ponask Lake, and south from Stull Lake (*see* Figure 002.1). Both northern and southern sides of the zone are bounded by very well developed shear zones parallel to greenstone belt boundaries. At Stull Lake, a 400 m wide sinistral shear zone hosted in mafic metavolcanics trends east and is located 0.8 km north of the intrusive contact with very coarse grained amphibolite, forming an intrusive breccia in medium-grained very quartz-rich trondhjemite. At Ponask Lake, a mylonitized to strongly foliated trondhjemite to quartz diorite exhibits a dextral shear zone of over 2 km width extending into both the granitoid and greenstones. This shear zone is similar to the shear found at the granite-greenstone contact in the Meen-Dempster Lakes metavolcanic-

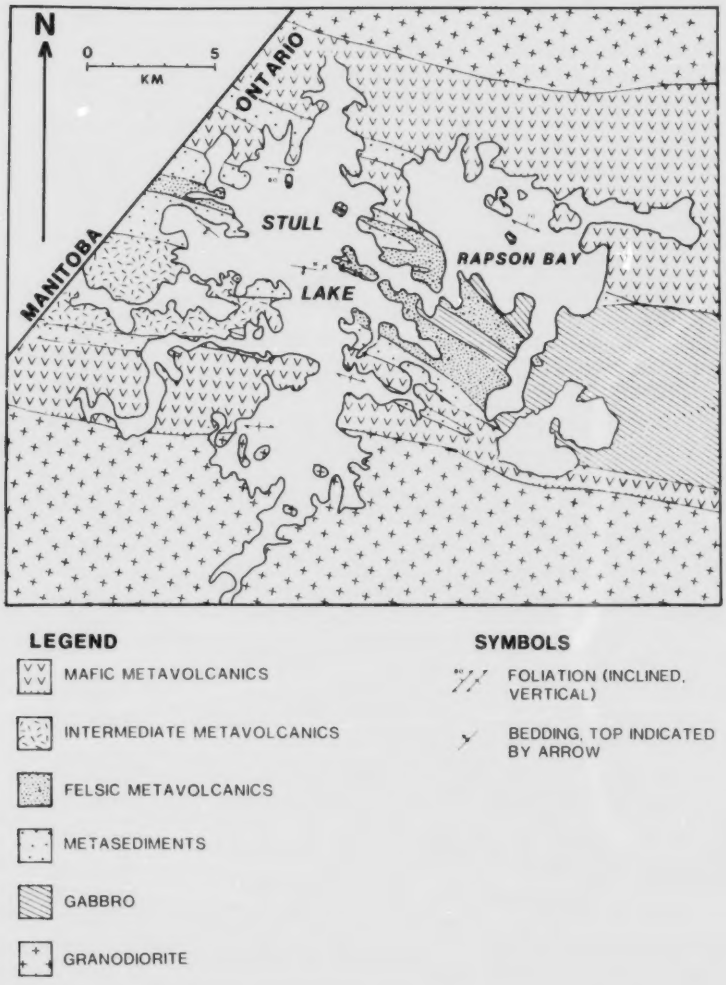

Figure 002.8. *Sketch map of the Stull Lake metavolcanic-metasedimentary belt. The contact between the metasediments and felsic pyroclastics is arbitrary (see text).*

metasedimentary belt in the Central Uchi Subprovince (Stott and Wallace 1984). Abundant mafic amphibolite xenoliths containing epidote-chlorite-biotite occur within massive tonalites and trondhjemites south of Stull Lake. The proportion of xenoliths decreases southwest as the composition of the granitoids changes from mesocratic hornblende biotite tonalite-granodiorite to leucocratic magnetite (>5 percent) (with minor hornblende+biotite) tonalite-trondhjemite. North of Ponask Lake, a laterally continuous sliver of strongly folded conglomerate of amphibolite grade was found within mylonitized trondhjemites. Xenoliths of mafic material were only observed in granitoids north of this sliver. Northward from Ponask Lake, mylonitized to massive trondhjemite to biotite trondhjemite grade into massive, undeformed biotite-bearing granites. Toward the centre of the transect, increasingly abundant pegmatite dikes cut all lithologies. These become increasingly coarse grained with the development of megacrystic plagioclase, microcline, and rutile in a pegmatitic graphic-textured quartz-plagioclase groundmass.

STULL LAKE

Location and Access

Stull Lake, located on the Ontario/Manitoba border at Latitude 54°23'N, was mapped at a scale of approximately 1:31 680 (1 inch to 1/2 mile) during July, 1987. Access to the lake is by float- or ski-equipped aircraft from Red Lake.

General Geology

The map area is underlain by Archean metavolcanics and metasediments, bounded to the north and south by granitoid batholiths.

Previous mapping of the area was done at a reconnaissance scale by Satterly (1938), and by Bennett and Riley (1969). Modifications to stratigraphy and structure are described (Figure 002.8).

The major supracrustal lithologies within the map area, proceeding from north to south (Figure 002.8) are:

1. an east striking, south-facing sequence of massive fine-grained mafic metavolcanic flows and fine-grained feldspathic wackes
2. a southeast-striking, southward-facing unit of interbedded boulder conglomerate, fine-grained feldspathic wacke, intermediate pyroclastics (tuffs, lapilli-tuffs, and tuff-breccia), and fine-grained felsic metavolcanics
3. an east-trending unit of fine-grained hornblende porphyroblastic massive and pillowed mafic flows. Due to extreme deformation of the pillows, a younging direction could not be determined

The conglomeratic rocks are polymictic with rounded to subangular pebbles to boulders and normal grading of clasts. Sandy interbeds to 10 cm thick contain crossbedding, scours, and load structures.

The coarse pyroclastics exhibit well developed grading and are matrix supported heterolithic units, probably originating by the debris flow mechanism with large pumiceous clasts at the top of depositional units. The environment is difficult to interpret in terms of proximity to the vent, although frequent alternation between unit types and the presence of ash flows and felsic flows suggests a moderately proximal environment (cf. Fisher and Schminke 1984).

Mapping by both Satterly (1938) and Bennett and Riley (1969) attempted to discern distinct boundaries between the felsic volcanic and sedimentary units across the belt. This proved to be impossible as these units are intimately intercalated. Present interpreted lithological contacts are based on the predominance of one rock type over another. The predominance of felsic metavolcanics and volcanic derived metasediments in the eastern part of the belt, and immature clastic metasediments in the west suggests a volcanic edifice was situated at the southwestern end of Rapson Bay with distal sedimentation occurring toward the western portion of the map area.

Structure

Foliation across the belt trends east-southeast and dips from 70° to 90° southwest. Northeasterly dips were noted in some parts of Rapson Bay.

Bedding was found to parallel foliation, and all units face south.

Mapping of mesoscopic folding in all units by Satterly (1938) indicated that the Stull Lake belt formed an anticline. On the basis of top reversals found in the northern portion of the belt, Bennett and Riley (1969) proposed a synclinal structure. However, consistent south-facing of all units, found in present mapping, indicates that the belt is likely a homoclinal sequence with an early mafic to felsic volcanic cycle overlain by a later mafic volcanic cycle.

Additional observations made during present mapping were:

1. F_1 folds exhibit tight to isoclinal morphology, trend in an easterly direction, and plunge moderately to steeply to the east. F_2 folds are commonly open to closed in form and plunge relatively steeply to the south. Local F_1-F_2 fold interference has resulted in the formation of dome and basin structures.
2. A possible pre-F_1 phase of folding may be suggested by: a) the presence of rootless isoclinally folded quartz veins rotated into parallelism with S_1 fabric; and b) an early S fabric which wraps around F_1 fold noses.
3. Later mesoscopic folding episodes cut all fabrics. The first trends northeast and has dextral offset. The second episode trends northwest and exhibits sinistral offset. Both of these episodes have given rise to abundant quartz-carbonate-tourmaline veining.
4. In Rapson Bay, steeply north-plunging warping of foliation is seen to overprint all fabrics, but was not found elsewhere.
5. Very strongly developed S fabric in the southern portion of the belt was found to correspond to westward plunging mesoscopic folds and dextral shearing best developed in the southern mafic unit. This fabric was not found to extend southward across the greenstone-granite contact.

The above observations indicate that the belt has been affected by at least two folding events.

SANDY LAKE

The Sandy Lake greenstone belt lies 280 km north of Red Lake. Access to the area is via float-equipped aircraft from Red Lake. Previous work in the area is largely the excellent mapping by Jack Satterly (1939).

The belt lies within the central part of the Sachigo Subprovince and consists of several distinct metavolcanic-metasedimentary sequences separated by shear zones (Figure 002.9). The belt is up to 8 km wide and extends east-west for 67 km along the full length of Sandy Lake.

Sandborn Bay Sequence

The Sandborn Bay Sequence forms the southern part of the Sandy Lake greenstone belt. It is bounded on the north by the Central Sandy Lake Shear zone and on the south by granitoid rocks of the North Trout Lake Batholith (Ayres 1974). The sequence extends from the western shore of Sandborn Bay to the islands in Sandy Lake south of Rahill Lake, a distance of 45 km. The basal unit is thin to thick bedded wacke pelite couplets, mainly deposited as A-E turbidites, occasionally with 10 to 15 m thick coarse (coarse to fine generally angular) sand bases. The pelites are Mg rich, based upon the presence of up to 70% coarse (up to 2 cm) cordierite in a cordierite hornfels aureole developed around gabbroic sills intruded along west-trending axial planar shear zones. The hornfels assemblage overprints a midamphibolite facies S fabric. The pelites are overlain by quartzose sedimentary rocks which consist of quartzose wacke and interbedded argillite, conglomerate, and lithic wacke. The quartzose wacke beds which are up to 2 m thick, and are overlain by an up to 15 cm thick argillaceous top. Primary structures in these rocks consist of a planar laminated base up to 15 cm thick, overlain by planar and trough crossbedded mid portions up to 1 to 1.5 m thick, succeeded by a planar laminated quartzose wacke, top up to 15 cm thick, which in turn is capped by massive poorly bedded, ungraded argillite. The quartzose sedimentary rocks

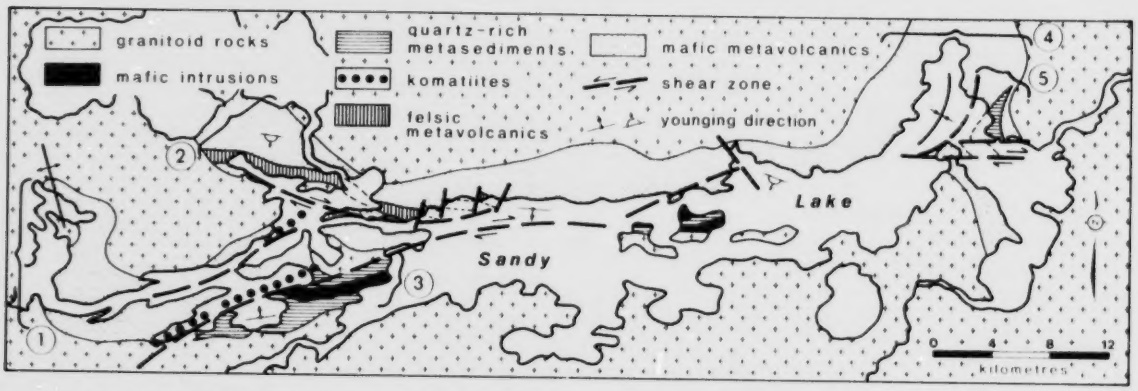

Figure 002.9. *Sketch map of the Sandy Lake greenstone belt.*

are up to 450 m thick and extend for about 14 km. Conglomerates contain clasts of chert, limestones, quartz arenite, and felsic and mafic metavolcanics.

The quartzose wackes vary from coarse to fine sand. The base of some beds consists of angular chert, felsic volcanic and quartz grains up to 5 mm in size. The rocks are in general mineralogically mature, but vary in textural maturity from very immature in minor basal portions to very mature in thick graded to nongraded beds.

Above the quartzose wackes is a 6 m thick contorted brecciated limestone bed containing no primary structures. The quartzose metasediment-carbonate association and primary structures suggest the sequence represents a platformal environment (cf. Hsu 1982, 1973).

The sequence grades eastward into deeper water sediments, represented by wacke-pelite couplets forming a monotonous sequence deposited by turbidity currents based upon primary structures.

The sequence is overlain, with some structural complications, by about 800 m of komatiitic flows which extend the length of Sandborn Bay. The komatiites are largely pillowed flows with some cumulate zones displaying cumulate 2 mm relict olivine grains and some secondary pseudospinifex formed of metamorphic tremolitic amphibole in talc-antigorite schist. The talc-antigorite schists on Satterly's (1939) map occur where the komatiitic unit has been affected by shearing.

On the northern shore of Pesew Island in central Sandy Lake, turbidites, correlated with unit 2, are overlain by 150 to 200 m of felsic quartz and feldspar-phyric pumiceous tuff and lapilli-tuff. The unit is massive to poorly graded and nonbedded. The presence of silicified pumice, the vertical succession of primary structures, reverse grading of pumice fragments, vertical variation in proportion of phenocrysts, and increasingly mafic composition of pumice upwards suggests that the unit is a subaerially deposited ash-flow erupted from a compositionally zoned magma chamber (cf. Fisher and Schminke 1984). This unit may correlate with the North Shore Sequence or may be similar to subaerial ash-flows of the Keewaywin Sequence which is described later. The unit was sampled for geochronology.

Western Sequence

This sequence extends west-southwest from the North West Arm Shear Zone for a distance of 19 km and north for 8 km. The southern boundary of the sequence is the West Arm Shear Zone and the northern and western boundaries are the granitoid plutons. The sequence consists (Figure 002.5) of tholeiitic and komatiitic flows (3000 m) overlain by metasediments. The mafic-ultramafic metavolcanics are pillowed flows with some ultramafic lapilli-tuff and tuff exposed at the eastern end of the West Arm on the northern shore. At this locality, ocellar structures are also present in the komatiites with irregular blobs from 2 to 30 cm in size with chill margins within komatiitic flows. The metasediments consist of 30 cm to 1 m thick massive poorly graded beds of quartzose wacke containing 80% quartz with 1 to 5 cm thick argillite tops. These wackes are intercalated with unusual conglomeratic beds 30 cm to 1 m thick with 10 to 16% grunerite-magnetite wacke matrix and 85 to 90% clasts consisting of 45% oxide iron formation and 40% quartz arenite.

Above this is a 30 m thick conglomerate unit with 10 to 20% grunerite-magnetite matrix, up to 10% quartz arenite clasts, 60% fine-grained quartz arenite and chert clasts, and 15% amphibolite clasts. The clasts are generally tabular in shape and subangular. No grading or bedding is apparent but the long dimension of the clasts parallels regional bedding. The clast lithologies and shapes bear some similarities to conglomerate of the Fig Tree Group in the Barberton Mountain Land and similarly to the conglomerates of the Sandborn Bay Sequence (cf. Heinrichs and Reimer 1977; Lowe and Knauth 1977).

North Shore Sequence

The North Shore Sequence extends east from North West Arm of Sandy Lake for a distance of 38 km to Fishtail Bay and varies in exposed width from 3000 to 5500 m. The sequence is bounded on the north, west, and east by granitoid rocks and on the south by the Central Sandy Lake Shear Zone. The sequence is south younging and consists, from base to top of:

1. pillowed tholeiitic flows, variably generally slightly saussuritized flows; thickness of flows varies from 30 to 100 m. The flows commonly are capped by 2 to 10 cm of chert or oxide facies iron formation.
2. North Shore Felsic Complex (felsic ignimbrites)
3. oxide facies iron formation

The North Shore Felsic Complex extends over much of the length of the sequence. On the shores of North West Arm, the unit is tuff to tuff breccia with metre-scale graded beds dominated by juvenile "cow dung" bombs. Pumice content increases eastward. Individual beds are 1 to 5 m thick with occasional fine crossbedded bases, and pumice rich tops. Normal grading of lithic clasts is well developed; reverse grading of pumice clasts also occurs. More than 20 depositional units were observed. Typical units grade upward from tuff breccia to tuff, with many simple tuff depositional units. The sequence contains quartz phenocrysts at the base and, at the top, only feldspar phenocrysts. The vertical succession of primary structures, from a crossbedded fine tuff base, through a massive unbedded poorly graded interior, a poorly bedded, poorly graded lapilli-tuff, to a tuffaceous top with abundant pumice, all suggestive of an ash-flow origin for the units (Fisher and Schminke 1984). The abundance of lithic fragments to the west suggests that these units represent a coignimbrite lag deposit (Wright *et al.* 1980). The crossbedded base represents base surge deposits (Sparks 1976; Sparks *et al.* 1973) whereas the upper poorly graded units represent cloud surge deposits (Wright *et al.* 1980). Detailed mapping revealed a zonal distribution of welding and vapor phase recrystallization suggesting the development of simple and compound cooling units. Silicified pumice fragments suggest subaerial deposition of the part of the unit in North West Arm (cf. Thurston 1980, and references therein). The transition from a rhyolitic base to andesitic top, the presence of composite fragments, and phenocryst variation suggest eruption from a compositionally zoned magma chamber (cf. Hildreth 1979; Smith 1979). The unit varies in thickness from 1500 m to less than 100 m, with the major thickness change occurring abruptly just east of North West Arm. At this location there is an abrupt fragment size change to tuff and lapilli-tuff and a grain size change decrease to the east along with a decrease to 6 to 12 depositional units. These features suggest that the western segment is caldera fill whereas the eastern sequence is extra caldera facies. In the extra caldera facies the ash flow is bounded above and below by oxide facies iron formation, suggesting that the extra caldera facies was in part deposited subaqueously. The unit is offset by north-northeast-trending *en echelon* shearing with sinistral offset.

Keewaywin Sequence

The Keewaywin Sequence occurs at the eastern end of Sandy Lake and is named after the native settlement on the southwestern shore of Keewaywin Bay (local name). The sequence is bounded on the west by a north-trending sinistral shear zone and on the north, south, and east by granitoid rocks. The sequence is about 4000 m wide at most.

Stratigraphically the sequence consists of:

1. basal oxide facies iron formation unit consisting of two 3 to 5 m thick units interlayered with actinolite chlorite schist of uncertain origin which may represent ultramafic flows.
2. andesitic tuff up to 600 m thick
3. quartz arenites with minor bedding, parallel andesitic dikes, and tuff beds forming a 900 to 1500 m wide unit. The unit consists of monotonously graded centimetre- to metre-scale beds of quartz arenite with minor quartz arenite conglomerate. This conglomerate is composed of coarse (3 to 5 mm) arenite matrix with rounded quartz grains and 30 to 50% rounded 2 to 10 cm quartz arenite clasts. Primary structures within the sequence include: hummocky cross-stratification (Duke 1985), trough crossbeds, planar crossbeds, coarse lag beds, scour structures, clast imbrication, normal to inverse grading, mud chip rip-up clasts, and soft sediment slump structures. The quartz arenites are mineralogically and texturally mature to supermature. Quartz arenite matrix conglomerates occur high in the section and contain angular to subangular pebbles of sericitized pumice, fuchsitic chert, banded, and massive chert, quartz-phyric felsic volcanic clasts, and weathered(?) fuchsitic chert clasts. The quartz arenites grade upward into felsic tuff and lapilli-tuff with much intercalation
4. felsic tuff and lapilli-tuff which show normal lithic fragment grading, reverse pumice grading, and the vertical succession of primary structures typical of ignimbrites (cf. Fisher and Schminke 1984). Silicification of pumice fragments suggest a subaerial deposition environment (cf. Thurston 1980, and references therein).

The quartz arenite-felsic tuff association passes gradationally southward into turbidites with moderate (15 to 20%) clay content and contains abundant (up to 80%) very mature quartz in the coarse fraction.

Facies Relationships

Within the quartz arenite sequence, hummocky cross-stratification represents shallow marine conditions above the storm wave base (Duke 1985, and references therein), while the crossbedded arenites to the northeast and east represent submarine fan to fluviatile conditions. Hence, the paleoshore lay to the north. The lateral and upward transition to quartz-rich texturally mature semipelites and psammites with grading, scour structures, and minor Bouma D division crossbeds (cf. Walker 1979) suggest a deeper water facies.

Structure

Younging directions and the stratigraphic packages in the map area have been defined above. The individual major sequences are separated by east-, northeast-, and northwest-trending brittle to ductile shear zones. The shear zones and their interrelationships are described below.

Shear Zones

North West Arm Shear Zone

The North West Arm Shear Zone trends west-northwest and shows dextral offset by mapping the transition from S into C fabric (Simpson and Schmid 1983). Narrow splays trending northward are present but their extent is uncertain due to lack of access to the indian reserve. The vertical component of movement on this shear zone is south-side-up. Shear zone related alteration consists of silicification and K-metasomatism (excess biotite in mafic flows) west of North West Arm. The presence of sulphide mineralization, trenching, and iron carbonate in the matrix of pyroclastics suggests good gold potential along this shear zone.

West Arm Shear Zone

This zone extends west-southwest along the West Arm from North West Arm for an uncertain distance. Offset is dextral and the zone is in turn offset by an east-trending sinistral shear zone. The vertical component of movement on this shear zone is south-side-up.

Central Sandy Lake Shear Zone

This shear zone extends east to east-northeast from Sandborn Bay along Sandy Lake to Fishtail Bay, a distance of 40 km, but may extend further east. Offset on the zone is dextral. The vertical component of movement on this shear zone is south-side-up based upon metamorphic assemblage data. The shear zone is probably long-lived because of the existence of: a) premetamorphic diorite sills which are spatially restricted to the vicinity of the shear zone; b) diorites which appear responsible for the contact metamorphism of cordierite-rich pelites in the Southern Sequence; and c) cordierite-rich rocks which were then sheared after the intrusion of the diorites.

Other Shear Zones

A shear zone trending east-northeast for 6.5 km through Fishtail Point has sinistral offset. This zone has no major alteration observed within it, although the zone is manifested by four 100 to 200 m spaced shear zones.

A major carbonatized sinistral shear zone, trending 155 m along the western shore of Fishtail Bay, has a width of 15 m.

A major shear zone trends east, with dextral offset, through Keewaywin Peninsula. This shear zone may be a continuation of the Central Sandy Lake Shear Zone. Subsidiary sinistral (R'?) shear zones are found on the islands to the west.

A north-trending shear zone, about 1 km wide and 5 km long, extends from a peninsula on the southern shore of Sandy Lake at the eastern end and exhibits sinistral offset. This shear zone probably has an east-side-up vertical component of movement. The zone has extensive carbonate alteration in basaltic and rare ultramafic rocks and contains undeformed fault-bounded blocks. A northeast-trending splay of this shear zone bounds the Keewaywin quartz arenites and offsets an iron formation on the eastern shore of Keewaywin Bay, about 6 km north of the Severn River exit.

Folding

Sandborn Bay Sequence

In the Sandborn Bay Sequence, opposing tops suggest the presence of small scale (100s of metres) east-trending folds along the northern shore of Rathouse Bay and in central Sandy Lake; however, the sequence faces dominantly north. This folding is interpreted to be shear folding related to large and small scale shear zones, based upon the proximity of the folds to the shear zones and their orientation. The southern sequence, however, does face dominantly to the north.

Western Sequence

The northeast younging direction in the sedimentary rocks of this sequence defines a north-northwest-trending anticline. Limited mapping coverage precludes further interpretation.

North Shore Sequence

Pillow forms, packing relationships, and flow architecture in mafic flows, normal grading of lithic fragments, reverse grading of pumice fragments, gas escape structures, variation in phenocryst size and type, define tops in felsic ignimbrites of the North West Arm Felsic Complex. On this basis the North Shore Sequence uniformly faces south. Ubiquitous bedding-parallel shear zones suggest a repetition or thickening of the stratigraphy, but no folds are postulated in the western and central parts of Sandy Lake.

Keewaywin Bay Sequence

In northern Keewaywin Bay, pillow top determinations and an axial planar north-trending shear zone suggest the presence of a north-trending syncline. The Keewaywin quartz arenite sequence is folded about an east- to east-northeast-trending synclinal axis defined by numerous primary sedimentary structures.

Refolded folds with dome and basin structure in iron formation and the presence of foliated granitoid clasts in conglomerate at Sandborn Bay suggest multiple deformations. Multiple folding of the iron formation and overprinted S fabric in mafic metavolcanics at Keewaywin Bay suggest a shear-zone-related folding event postdating the above multiple folding events. The sheared nature of the southern granite greenstone contact suggests some granitoids along the southern margin of the belt are pre- to syn-shearing.

Much of the structural geology of the Sandy Lake area is dominated by east-trending shear zones. Northeast- and northwest-trending subsidiary shear

zones break the area into subdomains, bearing uncertain stratigraphic and geochronologic relationships to one another. However, within the southern and Keewaywin Sequences, lithologies (quartz arenites, iron formation, komatiites) and stratigraphy are directly comparable to the 3 Ga platformal sequences at Eyapamikama Lake (dekemp 1987; Breaks *et al.* 1985, 1986) and the North Spirit Lake area (Corfu and Wood 1986). Stratigraphy of the North Shore Sequence with normal mafic to felsic volcanic cyclicity (Thurston 1986) suggests that this sequence may be younger than 3 Ga. As well, stratigraphy in the Southern and Keewaywin Sequences are transected obliquely by east-trending shearing whereas the North Shore Sequence is not. This suggests: a) a greater age for the Southern and Keewaywin Sequences; and b) a possible allochthonous character for the North Shore and Keewaywin Sequences.

DISCUSSION AND CONCLUSIONS

The Superior Province north of the Berens Subprovince has been subdivided (W. Weber, Geologist, Manitoba Department of Energy and Mines, Winnipeg, personal communication, 1987) as follows:

1. Gods Lake Domain: comprises granite-greenstone terrane extending from the Oxford Lake-Knee Lake-Gods Lake belt east to the Big Trout Lake greenstone belt in Ontario
2. Molson Lake Domain: comprises dominantly granitoid and migmatitic rocks and lies south of the Gods Lake Domain. This block extends from Molson Lake through to Winisk Lake in Ontario, including the region between Ponask and Stull Lakes. Granulite facies rocks occur on the southern margin of the domain in Manitoba
3. Island Lake Domain: a granite-greenstone terrane, which has been termed the Sachigo subprovince by Ayres *et al.* (1971) and Card (1986)

The absence of a platform sequence at Stull Lake suggests that this belt is not part of the Sachigo Subprovince, but is within the Gods Lake Domain. The fault-bounded nature of the Molson Lake Domain in the area examined in Ontario, coupled with the occurrence of granulites in Manitoba, suggests that the domain is block bounded on the southern side by a major thrust.

Most Archean greenstone belts have been assumed to have similar styles of cyclical volcanism with various types of mafic to felsic cycles (Dimroth *et al.* 1982; Thurston 1986). Major variables have been the presence or absence of komatiites, and the degree to which the sagduction model of Goodwin and Smith (1980) versus a thrusting model (de Wit 1982) for structural development is appropriate.

In the sagduction model, the higher specific gravity of volcanic rocks of greenstone belts overlying lighter sialic basement causes the volcanic rocks to subside in a variation of gravity-driven deformation, producing the synclinal form of many greenstone belts. The thrusting model of de Wit (1982) involves thrusting of lower mafic ultramafic sequences probably as a form of gravity-driven deformation brought about by the rise of central diapiric granitoids. A major consequence of the latter model is that most greenstone belts represent less than 2 km of stratigraphic thickness. The thrusting model also implies most greenstones were deposited in very shallow water.

Most Archean greenstone belts were assumed to have been deposited in deep water, the depositional environment becoming shallow water or subaerial only when a substantial thickness of strata have built up (Dimroth *et al.* 1982; Ayres and Thurston 1985). Greenstone belts in general were interpreted as narrow zones of intense volcanic activity with volcaniclastic debris shed into adjacent metasedimentary subprovinces (Ayres 1969a); Ayres and Thurston 1985). Metasediments in greenstone belts were considered to consist largely of resedimented (turbidite) facies wacke, mudstone-siltstone, and conglomerate (Ojakangas 1985). The depositional environment was submarine fan in greenstone belts and perhaps more distal in adjacent metasedimentary basins (Quetico etc.). Within some belts a transition from platform to trough sedimentation (Eriksson 1981) is displayed.

Rock types and primary structures which are indicative of shallow water platformal sequences, typical of passive margins in modern environments, were considered rare in the Archean. In fact, Archean carbonate sediments were worthy of a cataloging by Armstrong (1960) but Archean quartz-rich metasediments and quartz arenites were considered unusual (Donaldson and Jackson 1965; Schau 1977). Shallow water platformal sequences have generally been considered part of the development of relatively undeformed cover sequences such as the Huronian (Card *et al.* 1972) and the Witwatersrand basin (Pretorious 1986).

Quartz-rich metasediments and sedimentary carbonates form the lower part of distinctive Archean stratigraphic packages (Wood *et al.* 1986). The packages consist, from the base upward, of:

1. quartz arenites and conglomerates±stromatolitic carbonates with primary structures indicative of shallow water deposition
2. felsic ash-flows with evidence of subaerial deposition
3. iron formation including oxide and silicate facies. Primary structures, distribution, and textures suggest deposition in shallow water
4. komatiitic flows and pyroclastics with textural evidence of deposition in shallow water.

This distinct three or four part stratigraphic package has been termed a platform sequence (Wood *et al.*, in press). These platform sequences were suggested to form the lower sequence of several Sachigo Subprovince greenstone belts (Wood *et al.* 1986). In this project, the authors have recognized platform sequences as the lower stratigraphic unit in all Sachigo Subprovince greenstone belts, including Horseshoe Lake (Jensen, Article 017, this volume) (Figure 002.5). The available U/Pb geochronology (deKemp 1987; Corfu and Wood 1986; Corfu and Ayres 1987) indicates the few dated platform sequences are about 3 Ga old. Platform sequences may be a useful correlation tool for all major greenstone belts in Sachigo Subprovince.

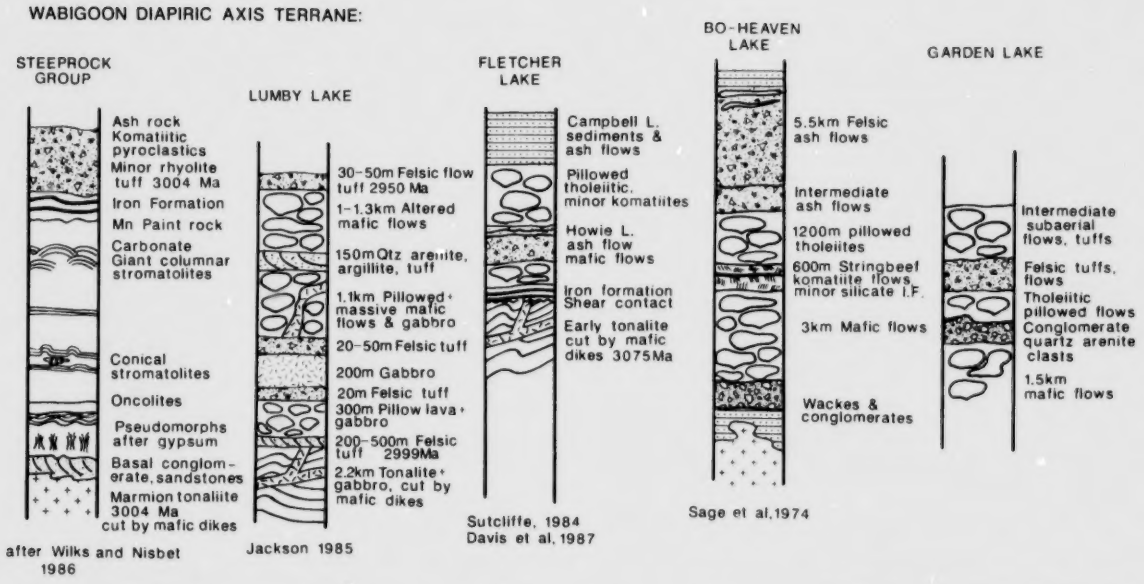

Figure 002.10. *Columnar sections of the Wabigoon Subprovince greenstone belts containing platform sequences.*

Platform sequences also occur at Atikokan (Williams and Nisbet 1986), Lumby Lake (Jackson 1985), Savant Lake in the Jutten group (Trowell 1986) and Caribou Lake. These occurrences on the northern and southern margins of Wabigoon Subprovince are about 3 Ga (Figure 002.10). Wabigoon greenstones above the platform sequences generally range from 2775 to 2700 Ma in age, leading Davis *et al.*, in press) to suggest that the platform sequences in the Wabigoon Subprovince were once continuous and were rifted apart by ocean basin development. The authors suggest herein that platform sequences may occur at Garden Lake and Bo-Heaven Lake. These belts may be over 2.7 Ga in age and if so, it is suggested that large parts of the Wabigoon Diapiric Axis Terrane (Edwards and Sutcliffe 1980) may approach 3 Ga in age. Therefore, the Diapiric Axis may represent a similar old sialic nucleus.

The Sachigo Subprovince is bounded on the north by a major shear zone at Ponask Lake which may extend southeast forming the northern boundary of the Wunnummin Lake belt (Stott and Janes 1985). The southern boundary of the Sachigo Subprovince is a shear zone extending from the Bearhead Fault south of North Spirit Lake (Wood *et al.*, in press) to the sheared southern boundary of the Horseshoe Lake greenstone belt (Jensen, Article 017, this volume) and perhaps eastward. Hence, the Berens Subprovince probably extends across Ontario as shown in Figure 002.1.

Stott *et al.* (1987) have postulated that the regional transpressive deformation along subprovince boundaries becomes progressively younger southward. This is based on U/Pb zircon ages at the Uchi-English River, Wabigoon-Winnipeg River, and Quetico-Wawa interfaces. Platform sequences are the oldest dated supracrustals in Superior Province greenstones (Davis *et al.* 1986). From the structural evidence, the age of the platform sequences, and the low abundance of platform sequences to the south, it is inferred that the Sachigo Subprovince is a sialic nucleus. It is older in part than surrounding the subprovinces, around which younger subprovinces accreted (Thurston 1987).

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Wabigoon Subprovince

003. Geological Studies in the Lake of the Woods Region and Western Wabigoon Subprovince, Northwestern Ontario

G.W. Johns

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

Until recently, geological mapping in the Lake of the Woods area consisted of a blend of reconnaissance surveys dating back 50 years, and some detailed geological surveys 15 to 20 years old. The lack of comprehensive mapping coverage has precluded a full appraisal of the mineral potential, structural history, lithology and stratigraphy of this classical area. This gap in the geologic picture of the Western Wabigoon Subprovince inhibited interest and exploration in this potentially resource-rich greenstone belt.

In order to rectify the situation, the Ontario Geological Survey initiated detailed geological mapping in 1979 in the Lake of the Woods area commencing with the eastern side of the lake. Maps and reports by Trowell (1986) and Johns (1987) joined with previous work by the Ontario Geological Survey (OGS) to the south (Trowell *et al.* 1980). In 1983, detailed studies of the gold occurrences in the northern Lake of the Woods area were initiated (Davies 1983) and continue to the present (Davies and Smith 1984; Smith 1984; Smith 1985; and Smith and Thomas 1986). In conjunction with the gold studies, detailed lithological and structural studies in the northern half of Lake of the Woods area commenced in 1984 and to the present the majority of the area has been mapped at a scale of 1:15 840 (Ayer 1984; Ayer 1985; Ayer and Sweeny 1986; Morrice 1986; Sanborn 1986; Ayer *et al.*, article 004, this volume; Buck and Ayer, article 005, this volume; Morrice and MacMaster, article 006, this volume).

Current mapping in the Chisholm Island area by Ayer *et al.* (article 004, this volume) has traced the Pipestone-Cameron Deformation Zone (PCDZ) across the area and outlined several splay faults from the main deformation zone. Southeast of the area significant gold occurrences are associated with the PCDZ, as well, the more significant gold showings within the Chisholm Island area are also associated with the deformation zone. The trace of the PCDZ is an important exploration target for gold mineralization.

Morrice and MacMaster (article 006, this volume) have documented a thick sequence of clinopyroxene-phyric (now largely altered to hornblende) mafic and intermediate metavolcanics in the Monument Bay area that may represent the stratigraphically highest metavolcanics in the Lake of the Woods area. New gold occurrences, two of which contain 52 ppm and 870 ppb gold, were discovered by Morrice and MacMaster (article 006, this volume) within shear zones north and west of Separation Point.

The work to date has resulted in a better understanding of the stratigraphy of the Lake of the Woods area and its stratigraphic similarity with the Kakagi Lake-Savant Lake part of the Wabigoon Subprovince. Volcanological studies in the Lake of the Woods area by M. Morrice and J.A. Ayer have outlined vent and proximal volcanic facies deposits that have high potential for volcanogenic base metal deposits. Structural studies by P.M. Smith, M. Sanborn and S. Buck have led to a better understanding of the deformation history of the northern Lake of the Woods area and how the structure relates to the gold mineralization. This knowledge of the stratigraphy, volcanology and deformational history of these supracrustal rocks and surrounding batholiths will aid in the further understanding of Archean greenstone belt development and tectonics.

Increasing interest in gold in the Dryden area prompted the Ontario Geological Survey to commence lithologic, mineral deposit and structural studies in that area in 1986 (Berger *et al.* 1987; Chorlton 1986). Additional work by B.R. Berger (article 013, this volume) has further defined the stratigraphic succession in Laval and Hartman Townships and shows the existence of an early period of thrusting.

As part of his regional studies in the Western Wabigoon Subprovince, G.W. Johns briefly examined 1700 km^2 in the Rainy Lake area west of Fort Frances (Johns, article 007, this volume). Portions of this area thought to be largely covered by Quaternary deposits had not been mapped within the past 100 years but surficial mapping by Bajc and Gray (1987) delineated significant outcrop of Archean supracrustal rocks. A volcanic stratigraphic sequence similar to that found within the Western Wabigoon Subprovince was outlined. A problematic conglomerate deposit within the northern Lake of the Woods area was examined (Johns, article 008, this volume) in order to better understand its stratigraphic setting and depositional history within the volcanic stratigraphy outlined by Ayer (1985). The conglomerate appears to be conformable within the Upper Diverse Unit of volcanic rocks and may have economic implication related to epigenetic mineral deposits.

The geological database in the Western Wabigoon Subprovince is among the most detailed and comprehensive in Ontario. Several areas of high mineral potential, however, remain to be mapped in detail and several structural and mineral deposit studies are planned for the coming years. Studies of specific problems related to stratigraphy, volcanology and other aspects of the geology of Archean greenstone belts and their surrounding batholiths will continue.

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004. Geology of the Chisholm Island Area, Lake of the Woods, District of Kenora

J.A. Ayer[1], R.I. Macfie[2], and Shane Buck[1]

[1]Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Graduate Student, University of Ottawa and Ottawa Carleton Geoscience Centre.

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INTRODUCTION

Field investigations in 1987 were within the central portion of Lake of the Woods and are in continuity with mapping in the northern part of the lake conducted from 1984 to 1986 (Ayer *et al.* 1985a, 1985b; Ayer and Gil 1986a, 1986b; Ayer and Sweeny 1986). An area of 310 km^2, bounded by Latitudes 49°28'N to 49°35'N and Longitudes 94°15'W to 94°35'W, was mapped at 1 inch to 1/4 mile scale (1:15 840) during the Summer of 1987.

The centre of the map area is 25 km south of Kenora and 26 km northwest of Sioux Narrows with access to the area by water from Lake of the Woods.

MINERAL EXPLORATION

Information on exploration activity is derived from the Resident Geologist's Files, Ontario Ministry of Northern Development and Mines, Kenora (RGFK).

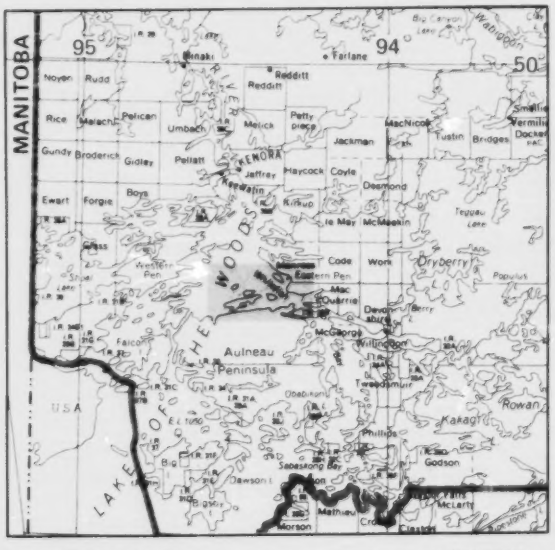
At the time of writing, September, 1987, there were three groups of claims in good standing in the map area. They include 33 claims around Gull Island, ten claims in the northern part of Blueberry Inlet on the Aulneau Peninsula, and a group of four claims in the Bear Bay area on the Eastern Peninsula.

The area has been explored for gold since the early 1880s during the Lake of the Woods "Gold Rush" (Beard and Garratt 1976).

Gold showings within the map area include the Ambrose Prospect, the Bath Island Occurrence, the Deadbroke Island Occurrence, and the Yellow Girl Bay Occurrence (Figure 004.1). Early work on the Ambrose (or Gull Island) Prospect resulted in a shaft sunk to a depth of 12 m, a 12 m long adit, and numerous trenches and pits all excavated around 1897 by the Ambrose Mine and Development Company of Ontario Limited. From 1934 to 1937, Lake Hill Gold Mines Limited did some additional trenching and stripping, and diamond drilled 16 holes for a total length of 1070 m. In 1965, Arjon Gold Mines Limited diamond drilled three holes totaling 368 m. In 1979, A. Hopkins had one hole diamond drilled to a depth of 92 m.

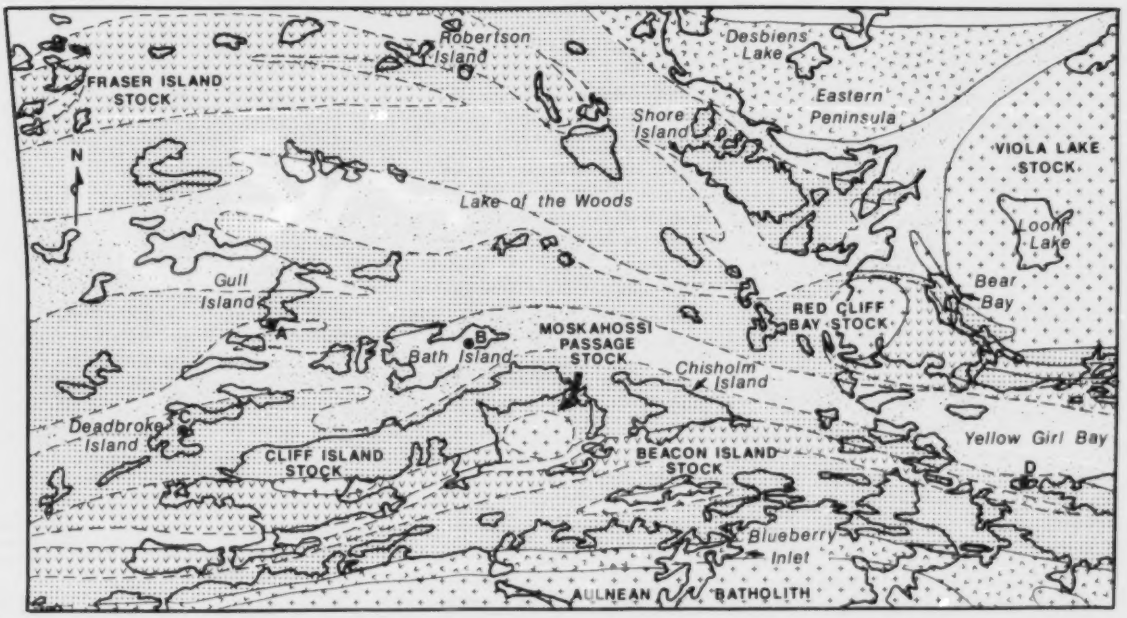
The Bath Island Occurrence (Figure 004.2) had a shaft sunk to a depth of 15 m, and numerous trenches and pits excavated from 1896 to 1898 by the Bath Island Mining Company Limited. The shaft was dewatered and the workings were cleaned and resampled by the Mining Corporation of Canada (1914) Limited in 1919.

At the Deadbroke Island Occurrence (Figure 004.1), a 6 by 3.6 m open cut and 3 by 3 m pit were



LOCATION MAP

Scale : 1:1 584 000 or
1 inch to 25 miles



Granitic intrusions

Warclub Group metasediments

UPPER DIVERSE UNIT

Interflow metasediments

Mafic to felsic metavolcanics

Mafic flows

LOWER MAFIC UNIT

Mafic flows

● Location of gold occurrences

A Ambrose (Gull Island) Prospect

B Bath Island Occurrence

C Deadbroke Island Occurrence

D Yellow Girl Bay Occurrence

0 1 2 3 4 kilometres

Figure 004.1. *Geology of the Chisholm Island area.*

excavated, and a 7.5 m long adit driven in 1892 by the Algoma Homestake Mining Company.

The Yellow Girl Bay Occurrence (Figure 004.1) was also held by Algoma Homestake Mining Company. The five trenches and two open cuts on this occurrence were probably excavated around 1892. In 1944, the Manowan Prospecting Syndicate cleaned and resampled the workings, and diamond drilled 11 holes. In 1981, Teck Explorations Limited conducted a ground electromagnetic survey and diamond drilled one hole to a depth of 63 m.

During the 1960s and 1970s, the area was explored for base metals by airborne and/or ground geophysical surveys in which the more interesting-looking conductors were investigated by diamond drilling.

In 1968, Norlex Mines Limited diamond drilled two holes with a total length of 307 m east of Robertson Island. Also in 1968, Cominco Limited diamond drilled two holes totaling 137 m east of Desbiens Lake on the Eastern Peninsula. In 1970, Kerr Addison Mines Limited drilled seven holes totaling 730 m around Desbiens Lake. Hudson Bay Exploration and Development Company Limited drilled two holes totaling 188 m southwest of Shore Island in 1975 and six holes totaling 232 m in Yellow Girl Bay in 1976.

PREVIOUS GEOLOGICAL WORK

Lawson (1885) produced the first published geological map of the Lake of the Woods Area. Parts of the area were included in 1 inch to 1 mile scale (1:63 360) geological maps by Thomson (1937) and Frazer (1945). More recent 1 inch to 1/4 mile scale (1:15 840) geological maps of the surrounding area include Davies (1967, 1983) to the northeast and west respectively, Johns and Rickey (1982) to the east, Johns and Davison (1983) to the southeast, Ayer *et al.* (1985a, 1985b) to the northeast, and Ayer and Gil (1986a, 1986b) to the north.

Graduate student research in the area includes a Ph.D. thesis on the Aulneau Batholith at 1:50 000 scale by Ziehlke (1974), an M.Sc. thesis by Car (1980) in the northern part of the map area, and a structural Ph.D. thesis by Brown (1984) which included all of the map area at a scale of 1 inch to 1/2 mile (1:31 680).

GENERAL GEOLOGY

The map area (Figure 004.1) is underlain by Archean supracrustal and intrusive rocks within the western portion of the Wabigoon Subprovince and are cut by several northwest-trending Proterozoic diabase dikes. The supracrustal rocks consist of easterly trending volcanic and sedimentary rocks metamorphosed to greenschist facies rank. These rocks are intruded by the Aulneau Batholith, the Viola Lake and Red Cliff Bay Stocks, and several smaller stocks throughout the map area (Figure 004.1). The larger intrusions have amphibolite facies rank contact metamorphic aureoles up to 2 km wide.

The supracrustal rocks have been subdivided into three major stratigraphic units. They are, from oldest to youngest: the Lower Mafic Unit, the Upper Diverse Unit, and the Warclub Group.

LOWER MAFIC UNIT

The oldest rocks in the map area have been designated the Lower Mafic Unit. They consist of pillowed to massive mafic flows ranging from aphyric to plagioclase porphyritic basalt. The latter rock is distinctive with coarse-grained equant plagioclase phenocrysts up to 3 cm in size (leopard rock). This unit occurs in two separate horizons. The unit in the northeast is up to 3 km wide and extends beyond the map area to the north and west onto the Western Peninsula (Ayer and Gil 1986a, 1986b). It has been correlated with similar units in Bigstone Bay and Clearwater Bay in the northern part of Lake of the Woods (Ayer and Gil 1986a, 1986b; Ayer and Sweeny 1986). The southern horizon is up to 2 km wide and is intruded to the south by the Aulneau Batholith. It extends east of the map area where it was identified as the Snake Bay Formation (Johns 1987).

UPPER DIVERSE UNIT

The Lower Mafic Unit is conformably overlain by a highly diverse, predominantly metavolcanic unit, designated the Upper Diverse Unit. The unit is a lithologically and structurally complex intermixture of three subunits consisting of: a) aphyric to locally variolitic pillowed to massive mafic flows; b) mafic to intermediate plagioclase, with or without pyroxene-phyric flows, flow breccias, and debris flows, and intermediate to felsic, plagioclase, with or without quartz-phyric debris flows and pyroclastics; and c) sedimentary rocks interbedded with metavolcanics of the Upper Diverse Unit.

Three horizons of the mafic subunit (subunit 1), up to a maximum of 3 km thick, occur within the Upper Diverse Unit. One of these, on the eastern side of the map area, extends east of the map area and has been identified as the Black Lake Volcanics consisting of tholeiitic to komatiitic basalt (Johns 1987).

The mafic to intermediate flows of subunit 2 typically contain medium-grained lath-shaped plagioclase phenocrysts and locally medium- to coarse-grained equant amphibolitized pyroxene phenocrysts. The flows are commonly pillowed and amygdaloidal with quartz and/or carbonate vesicles up to several centimetres. Intermixed with these flows are fragmental volcanic rocks which occur as pillow breccia, pyroclastic breccia, and debris flows. Locally, the fragmental rocks are felsic to intermediate, with clasts and matrix containing plagioclase with or without quartz phenocrysts. Some of these are debris flows with heterolithic mafic to felsic fragments and locally derived sedimentary clasts. Other felsic to intermediate fragmental rocks are pyroclastic in origin with monolithic fragments ranging in size and sorting from tuff-breccia and lapilli-tuff to bedded crystal tuff and thinly laminated siltstone.

SEDIMENTARY UNIT

Relatively thin horizons of metasediments occur locally at the contact between metavolcanic subunits of the Upper Diverse Unit. The horizons are up to several hundred metres thick and commonly interbedded with metavolcanics. They consist of fine-grained, thinly bedded quartz-poor feldspathic and tuffaceous wacke interbedded with very fine grained thinly laminated siliceous siltstone. Magnetite ironstone beds up to 10 cm thick occur interbedded with wacke and siltstone north of Robertson Island.

A horizon of granitoid clast conglomerate occurs in the northwestern corner of the map area and consists of rounded granodiorite cobbles in a sparse fine-grained chloritic matrix. The unit is similar to two other horizons north of the map area (*see* Johns, Article 008, this volume) but it is more deformed and no bedding features were observed.

WARCLUB GROUP

Uppermost in the stratigraphy are metasedimentary rock units which are continuous with those to the east of the map area identified as belonging to the Warclub Group (Johns 1987). They occur in two separate horizons up to 3 km thick trending easterly across the central portion of the map area (Figure 004.1).

In most localities, the Warclub Group metasediments clearly overlie the metavolcanics of the Upper Diverse Unit but in some localities, such as in the Shore Island area, the metasediments interdigitate with felsic to intermediate metavolcanics of the Up-

per Diverse Unit indicating that sedimentation and volcanism were in part contemporaneous.

Metasediments of the Warclub Group are fine- to medium-grained turbidites with bedding from 0.5 to 8 m thick and all A to E divisions of the Bouma sequence locally present. Wackes typically contain rounded feldspar, quartz, and lithic grains.

North and northwest of the Viola Lake Stock the Warclub Group metasediments are thinner bedded (up to 30 cm), finer-grained, and more siliceous than the turbidites described above.

SYNVOLCANIC INTRUSIONS

The Lower Mafic and Upper Diverse Units are intruded by mafic sills up to several hundred metres thick which locally differentiate into ultramafic rock at the base and gabbro to leucogabbro at the top. The sills (not shown on Figure 004.1) are most abundant at the eastern end of the Lower Mafic Unit in the northeast and the Upper Diverse Unit north of the Aulneau Batholith.

All supracrustal units were intruded by intermediate to felsic, plagioclase±quartz±amphibole porphyry dikes.

GRANITIC INTRUSIONS

About 20 percent of the map area is underlain by intermediate to felsic intrusive rocks ranging from quartz diorite to granite. The oldest, are pre- to syntectonic and occur within the Aulneau Batholith. The Batholith is a large 1250 km^2 multiphased intrusion extending up to 30 km south of the map area (Ziehlke 1974). Dating has indicated the oldest phase is 2716.8+4.9/-2.8 Ma and the youngest phase is 2709.6+2.9/-1.5 Ma (Davis and Edwards 1986). In Ziehlke's (1974) lithological scheme the portion of the Aulneau within the map area is encompassed by a single unit of trondhjemite.

Current mapping indicates that this area is underlain by strongly foliated quartz diorite intruded by foliated tonalite and granodiorite. Small lenticular bodies of weakly foliated to unfoliated granodiorite and quartz diorite intrude strongly foliated granitoid and country rock along the margin of the Batholith.

Possibly related to these younger unfoliated phases are massive to weakly foliated granodiorite stocks which occur 1 to 3 km north of the Batholith (Figure 004.1).

Two distinctive massive granodiorite intrusions containing potassium feldspar megacrysts occur in the eastern part of the map area. The Viola Lake Stock is remarkably homogeneous, apart from marginal quartz monzodiorite apophyses in the south, with fewer or no potassium feldspar megacrysts. The Red Cliff Bay Stock is also predominantly alkali feldspar megacrystic granodiorite and it grades into potassium feldspar porphyritic monzonite near the southern margin.

STRUCTURAL AND ECONOMIC GEOLOGY

Details on the structural and economic geology of the map area are covered in more detail in a separate paper (Buck and Ayer, Article 005, this volume). Briefly, the structure consists of numerous tight to isoclinal upright folds of at least two different generations which have resulted in many reversals of facing direction in the supracrustal rocks.

The Pipestone-Cameron Shear Zone (PCSZ) can be traced into the map area from the southeast. It extends northwesterly across the central portion of the map area as a zone of highly schistose and altered rock up to 1.5 km wide. Smaller northeast- to southwest-trending high strain zones, up to several hundred metres wide, occur throughout the map area.

A broad zone of contact strain up to 2 km wide extends across the southern part of the map area centred on the northern contact of the Aulneau Batholith.

The more significant gold showings (Ambrose, Bath Island, and Yellow Girl Bay) occur in relatively close proximity to the PCSZ in east- to northeast-trending narrow shear zones which may be splays off the PCSZ.

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005. Structural and Metallogenetic Studies, Lake of the Woods Area, District of Kenora

Shane Buck and J.A. Ayer

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

This report summarizes part of an ongoing metallogenetic and structural study of the Lake of the Woods region of northwestern Ontario. Field work during the Summer of 1987 was concentrated on the east-central part of Lake of the Woods, north of the Aulneau Batholith and south of the Barrier Islands (Figure 005.1). The present project was carried out in conjunction with detailed geological mapping at a scale of 1:15 840 by J.A. Ayer. The aim of the integrated approach of this project is to contribute to the development of a structural and stratigraphic framework for the Lake of the Woods region as well as describing mineralization in the area and its relationship to both stratigraphy and structure.

GENERAL GEOLOGY

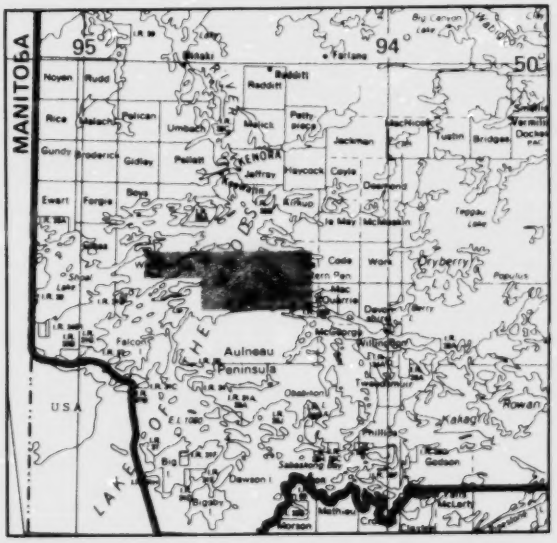
Because this report concentrates on the structural and economic geology of the "Chisholm Island" area (Figure 005.1), only a brief description of this regional geology will be included. For a detailed description of the general geology of this area the reader is referred to J.A. Ayer *et al.* 1987 (Article 004, this volume).

The regional stratigraphy consists of Archean supracrustal rocks which include mafic to felsic metavolcanics, synvolcanic intrusions, and wacke. These supracrustal rocks have been intruded by the early to syntectonic Aulneau Batholith and the late to posttectonic Viola Lake and Red Cliff Bay Stocks. With the exception of the posttectonic stocks and several early Proterozoic diabase dikes, all of the rocks in the area have been subjected to multiple folding and/or shearing events.

Throughout most of the area, the supracrustal rocks have been metamorphosed to lower to middle greenschist facies rank. However, a narrow aureole of amphibolite facies rank metamorphism exists at the northern margin of the Aulneau Batholith and narrow zones of hornfels metamorphism were observed near the contacts of the Viola Lake and Red Cliff Bay Stocks.

STRUCTURAL GEOLOGY

The Chisholm Island area has a complex, multiphase history of deformation which involves both folding and shearing. Presently, the timing of successive folding and shearing events and the relationship between folding and shearing is not clearly understood. It is possible to recognize at least two separate folding events and two separate periods of displacement along major shear zones. The designation of F_1 and F_2 in this preliminary report refers only to the relative timing of the folding described here. It is not meant to infer that F_2 is the second regional folding event but instead that F_2 folds formed later than F_1 folds.



LOCATION MAP

Scale : 1:1 584 000 or
1 inch to 25 miles

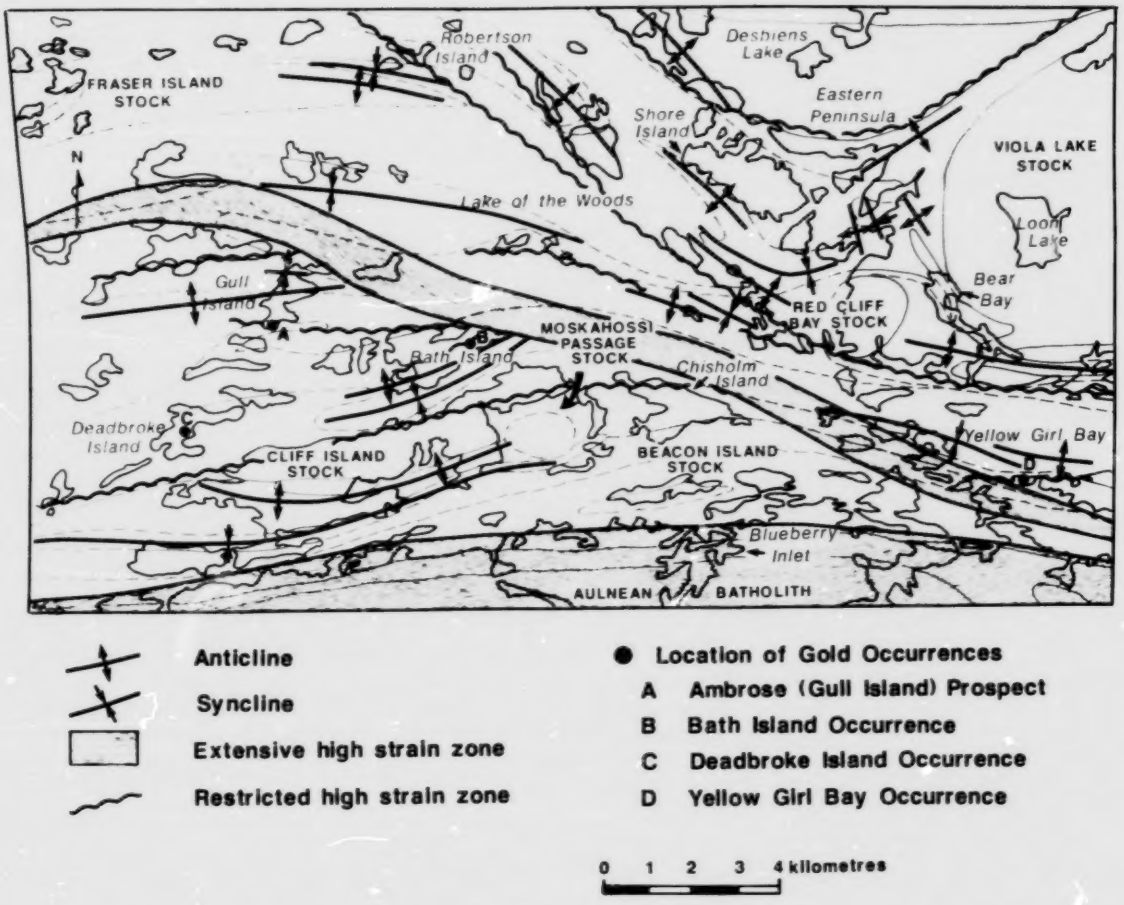


Figure 005.1. Structural geology of the Chisholm Island area.

FOLDING

Recognition of both regional and smaller scale folding was aided in the field by the abundance of reliable stratigraphic top indicators in both the volcanic and sedimentary units. Low water levels in Lake of the Woods added greatly to outcrop exposure and ease in identifying top indicators as well as in some cases, individual fold hinges.

The earliest recognized folds are west trending, regional scale synclines and anticlines (Figure 005.1), with steep axial surfaces and subhorizontal axes. Recognition of folds is based on top reversals, repetition of stratigraphy, and the presence of a regional flattening fabric which is at either a low angle or parallel to bedding and is assumed to exist axial planar to F_1 folding. While small scale F_1 folds were not reliably identified during the present mapping, examples have been described by Brown (1984). The lack of recognizable small scale F_1 structures may be due in part to overprinting and reorientation by later deformation events. In many cases the trace of F_1 axial surfaces has been obscured or displaced by shearing and posttectonic intrusions. Several of the F_1 folds outlined in the eastern part of the area have been traced further eastward into the MacQuarrie Township area (Johns and Richey 1982). Regional scale folding similar to that described here has been observed throughout the Lake of the Woods area (Ayer and Sweeny 1986; Sanborn 1986).

A second phase of folding can be readily identified in the field as steeply plunging, tight to isoclinal folds with steeply dipping axial surfaces. These structures fold the earlier flattening fabric and are defined by reversals in younging direction, bedding-cleavage relationships, and clearly exposed fold hinges. These F_2 folds are accompanied by the development of a moderate to strong axial planar fabric which is typically a close spaced cleavage which crenulates the earlier flattening fabric. Locally, slip along the axial planar cleavage has caused transposition and reorientation of bedding.

F_2 folding was most readily identified southwest of the Pipestone-Cameron Shear Zone (Figure 005.1), where several large scale, northeast- to east-trending synclines and anticlines were outlined in the sedimentary units exposed on Gull and Bath Islands. Northeast of the Pipestone Cameron Shear Zone (Figure 005.1), several folds were observed in

schistose and ferroan carbonate altered rocks associated with two high strain zones. Although these folds are steeply plunging with subvertical axial surfaces, it is not clear whether or not they are related to F_2 folding outlined to the southwest or to transcurrent displacement within the high strain zones.

Top reversals in the sedimentary units north of Red Cliff Bay outline several tight folds closely associated with the Red Cliff Bay and Viola Lake Stocks. These folds are northwest-trending with steeply dipping axial surfaces and deform an earlier bedding parallel fabric.

Similar style folds with north-trends have been recognized east of the Viola Lake Stock (Johns and Richey 1982). The close association of these folds to the Viola Lake and Red Cliff Bay Stocks and their northwest trend suggests that they may not be related to the east-trending F_2 folds recognized throughout the west of the study area but instead, may be related to the intrusion of these late to post-tectonic stocks.

HIGH STRAIN ZONES

Discrete high strain zones are common in the area of investigation. The dominant zone is the Pipestone-Cameron Shear Zone (PCSZ), a wide zone of schistose and ferroan carbonate altered rock that has been traced southeast of the Chisholm Island area through the Long Bay-Lobstick Bay area (Johns and Davison 1983), the Flint-Cameron Lakes area (Buck 1986) and the Pipestone Lake area (Edwards 1980), for a strike length greater than 100 km. Although a zone of similar deformation and alteration style has been outlined in the Monument Bay area (Morrice, Article 006, this volume), continuation of the PCSZ west of the present study area awaits continued detailed geological mapping.

In the Chisholm Island area, the PCSZ is generally northwest to west trending and varies in width from 500 to 1500 m. Ferrcan and calcium carbonate alteration is present throughout the PCSZ, both as quartz+carbonate veining parallel to the schistosity and also as a pervasive alteration in the more highly strained rocks. In the southeastern part of the PCSZ S-C shear fabrics, extensional crenulation cleavage and rotated boudinage were observed in vertical exposures. The asymetry of these structures, accompanied by a subvertical stretching lineation, indicates a south-side-up sense of displacement. Elsewhere throughout the PCSZ S-C shear fabrics, extensional crenulation cleavage, rotated phenocrysts, rotated boundinage, and Z-shaped shear folds were observed on horizontal exposures and indicate subhorizontal dextral displacement. Dextral displacement is also indicated by the displacement of a northeast-trending sedimentary unit north of Chisholm Island (Figure 005.1). With the exception of rare subhorizontal stretching lineations within the PCSZ, stretching lineations in both highly strained and less deformed rocks in the study area are steep westerly plunging.

The small scale structures outlined above suggest that the PCSZ formed originally during a vertical tectonic event in which the southern side was displaced upward relative to the north. This same zone of high strain was later reactivated during a regional dextral transcurrent shearing event.

Southwest of the PCSZ, several smaller zones of strongly foliated rocks were outlined (Figure 005.1). These zones of high strain differ from the PCSZ in that pervasive ferroan carbonate alteration is rare and evidence for transcurrent displacement was not observed. Three zones of highly strained rocks were outlined north of the PCSZ. These zones more closely resemble the PCSZ in that pervasive ferroan carbonate alteration is common and transcurrent displacement was observed. These zones converge on the PCSZ in the Fog Island area and may represent splays off of the dominant shear zone.

A contact strain aureole is found at the northern margin of the Aulneau Batholith. Both the granodioritic northern phase of the batholith and amphibolitized supracrustal rocks are characterized by a steeply dipping foliation and vertical to steep west plunging stretching lineations. The presence of small, less than 1 m dextral transcurrent shear zones, rare horizontal stretching lineations, and asymmetric augen structures in gneissic portions of the granodiorite suggest that this high strain has also been reactivated by regional transcurrent shearing.

STRUCTURAL SUMMARY

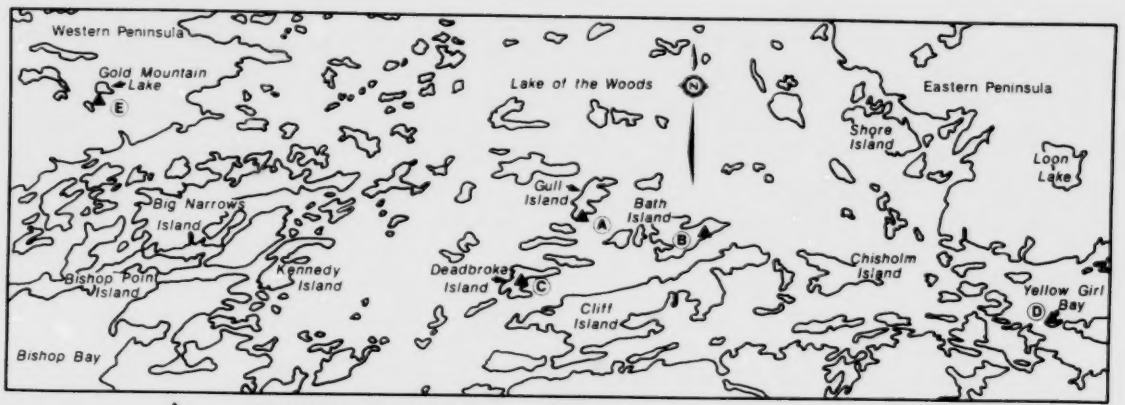
Although the complex deformational history of the Chisholm Island area is not clearly understood, several general observations can be made.

1. An early axial planar fabric associated with subhorizontal regional folds has been folded by smaller steeply plunging folds.
2. The Pipestone-Cameron Shear Zone and smaller shear zones north of the PCSZ show evidence of an early south-side-up vertical displacement which is overprinted by dextral transcurrent shearing. It is suggested here that the early vertical displacement may be related to emplacement of the Aulneau Batholith.
3. Foliation in the strain aureole associated with the Aulneau Batholith has also been overprinted in places by dextral transcurrent shearing, suggesting that emplacement of the northern phase of the Aulneau Batholith is postdated by regional transcurrent shearing.

ECONOMIC GEOLOGY

All gold showings within the study area, and a single showing outside of the area, the Gold Mountain showing (Figure 005.1), were investigated as part of ongoing metallogenetic studies in the Lake of the Woods area. Information on past work which is included in this report has been derived from the Assessment Files, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kenora.

The Gull Island showing is located on the southwestern peninsula of Gull Island at the western part of the Chisholm Island map area (Figure 005.2). The property has been worked discontinuously since 1895 when it was known as the Ambrose Mine which consisted of several trenches, one 12 m shaft, and a



▲ LOCATION OF GOLD OCCURRENCES

- A Gull Island Occurrence
- B Bath Island Occurrence
- C Deadbroke Island Occurrence
- D Yellow Girl Bay Occurrence
- E Gold Mountain Occurrence

Figure 005.2. *Location of gold showings.*

12 m adit. Later work included 1070 m of diamond drilling by Lakehill Gold Mines Limited in 1937 and 368 m of diamond drilling by Arjon Gold Mines Limited in 1965. During 1972 and 1973, geological mapping and a geophysical survey were completed by C.J. Kuryliw. More recent work included 98 m of diamond drilling by A. Hopkins in 1979 and outcrop stripping and sampling by A. Wilson in 1984. Visible gold has been reported in both drill core and surface samples and was observed during the present study in waste from the shaft. The best assays reported from assessment files for this showing are 6.06 ounces gold per ton from surface samples and 0.77 ounce gold per ton from drill core.

The showing is located near the contact of wacke of the Warclub Group (Ayer *et al.*, Article 004, this volume) and a 200 m wide quartz-plagioclase porphyritic dike. Both the porphyry and wacke have been deformed by an east-trending high strain zone which transects the southern part of Gull Island and can be traced further east onto Bath Island (Figure 005.1). Wacke and intermediate volcanic units north of this zone have been folded about a west-trending, steeply plunging syncline (Figure 005.1). Tight, steeply plunging folds were also observed in wacke southwest of the showing.

Gold mineralization is associated with several 1 to 2 m thick quartz-plagioclase porphyritic dikes within the wacke found south of the larger porphyry. These smaller dikes are conformable to the strong foliation within the sheared wacke, and although they pinch and swell along strike, they remain continuous for greater than 400 m. Trenching and sampling has been focused on these dikes which have been brecciated by crosscutting, mineralized quartz and quartz+ferroan carbonate veins. Mineralization occurs as disseminated pyrite, chalcopyrite, galena, and visible gold in the veins and porphyry.

The Bath Island Occurrence is located on the eastern side of Bath Island (Figure 005.2) within well bedded wacke crosscut by plagioclase and quartz porphyritic dikes. South of the showing the metasediments have been folded by several northeast-trending, steeply-plunging anticlines and synclines.

Mineralization at the showing consists of disseminated pyrite in 1 to 2 m wide, east-trending zones of highly strained and ferroan carbonate altered wacke, and also in irregular quartz veinlets up to 10 cm wide within a highly strained felsic dike. Underground and surface sampling was conducted by the Mining Corporation of Canada Limited in 1919. The highest assay reported from underground sampling was 0.12 ounce gold per ton. A higher assay of 0.73 ounce gold per ton was reported from surface sampling. The average assay value for all surface sampling was 0.023 ounce gold per ton.

The Deadbroke Island Occurrence is located at the eastern end of Deadbroke Island (Figure 005.2), within heterolithic intermediate pyroclastic metavolcanics which range from tuff-breccia and lapilli-tuff to fine-grained, thinly bedded crystal tuffs. In the vicinity of the showing, the intermediate metavolcanics are locally cut by thin fine-grained biotite alteration zones which give the rocks a dark appearance.

Mineralization occurs as disseminated pyrite within irregular quartz veins in and around two east-trending quartz-biotite porphyritic dikes. Thomson (1937) reported traces of chalcopyrite and galena in samples of quartz found in a dump at the occurrence. He indicates that 75 tons of ore were reportedly removed from the open cut with assays ranging from 0.35 to 6.65 ounce gold per ton.

The Yellow Girl Bay Occurrence consists of five trenches and two open cuts on a small island in Yellow Girl Bay (Figure 005.2). The area is underlain

by intermediate plagioclase-phyric and aphyric mafic flows cut by plagioclase+quartz porphyritic dikes. The occurrence is located in a wide high strain zone within which the rocks are altered by silicification and ferroan carbonate. Mineralization occurs as disseminated pyrite in silicified zones and as disseminated pyrite and arsenopyrite in quartz+ferroan carbonate veins cutting the silicified zones.

The property was drilled by the Monowan Prospecting Syndicate in 1944 who reported assays of 0.28 and 0.25 ounce gold per ton in two separate holes. Six grab samples were collected from various locations in the occurrence during the present study. A sample of disseminated pyrite and arsenopyrite from a silicified zone assayed 0.21 ounce gold per ton. The other samples all retained less than 0.01 ounce gold per ton (Geoscience Laboratories, Ontario Geological Survey, Toronto).

Each of the gold showings investigated in the Chisholm Island area are located in high strain zones spatially associated with the PCSZ. The presence of gold showings within the PCSZ, southeast of the Chisholm Island area has been documented (Buck 1986). The Gold Mountain showing is located several kilometres west of the PCSZ and was investigated as an example of a gold occurrence outside of the influence of this regional scale shear zone. As part of this investigation, the geology of an area adjacent to the showing was mapped at a scale of 1:3600.

The Gold Mountain showing is located on the Western Peninsula, southwest of the Chisholm Island Map area (Figure 005.2). Work on this showing began in the early 1890s when a shaft and several trenches were excavated. From 1973 to 1976, geological mapping and a geophysical survey were completed by C.J. Kuryliw. At the same time, 209.0 m of diamond drilling was done with the highest assay result 2.13 ounces gold per ton. Further diamond drilling was done in 1977 by Cominco Limited. This company drilled 197.8 m with a highest assay of 0.14 ounce gold per ton. C.J. Kuryliw drilled 46.6 m in 1983 with a highest assay value of 0.177 ounce gold per ton. In 1986 and 1987, the Gold Mountain showing was explored extensively by Mountain Lake Resources Incorporated. Geological mapping, geophysical and geochemical surveys, and ten diamond-drill holes were completed. The highest assay from surface chip samples was 0.479 ounce gold per ton, and from drill core was 0.484 ounce gold per ton.

The local geology in the area of the showing consists of interbedded mafic to felsic metavolcanics, wacke, siliceous mudstone and siltstone and a granodiorite clast-bearing conglomerate. The metavolcanics and finer grained metasedimentary units have been intruded by several plagioclase-quartz porphyritic dikes, and folded about a northeast-trending anticline. Similar conglomerate units east of the Gold Mountain area have been described by Ayer and Gil (1986a, 1986b) and Johns (Article 008, this volume) and may unconformably overlie the volcanic stratigraphy.

The Gold Mountain showing lies within a northeast-trending, steeply dipping high strain zone at the contact between fine-grained siliceous mudstone and siltstone and a plagioclase-quartz porphyry intrusion. The metasediments have reacted to the deformation in a ductile fashion with the formation of a strongly developed slaty cleavage parallel to bedding and minor shallow west-plunging folds. The porphyry has reacted in a brittle fashion and is brecciated by numerous mineralized quartz veins. Mineralization consists of disseminated pyrite and galena in white quartz veins within the porphyry. Only minor ferroan carbonate was observed within the porphyry; however, the metasediments south of the contact are altered by ferroan carbonate, and geochemical mapping by Mountain Lake Resources Incorporated indicates a ferroan carbonate anomalous zone surrounding the showing.

Several small (1 to 2 m) high strain zones, parallel to the high strain zone at the showing, were outlined in the surrounding areas. These zones were defined by the development of an intense schistosity and a steep, west-plunging stretching lineation. A larger high strain zone, 150 to 200 m south of the showing, is defined by a distinct northeast-trending topographic low up to 100 m wide. Outcrops of biotite-rich wacke within this low area are schistose and strongly altered by ferroan carbonate. This area is also indicated by a geochemical anomalous zone.

SUMMARY OF ECONOMIC GEOLOGY

Each of the gold occurrences investigated during this study show the following general characteristics:

1. In all cases, gold mineralization occurs within zones of highly strained rocks.
2. With the exception of the Gold Mountain showing, the high strain zones in which mineralization occurs are spatially related to the PCSZ.
3. In all cases, mineralization is associated with alteration by silicification and/or ferroan carbonatization.
4. With the exception of the Yellow Girl Bay Occurrence, mineralization occurs in quartz or quartz+carbonate veins within felsic dikes.
5. The Gull Island and Gold Mountain showing and the Bath Island Occurrence are each in close proximity to large scale folds. The association of gold mineralization and folding has been well documented at several gold camps in Ontario (Colvine *et al.* 1984).

Similar characteristics have been observed at gold occurrences throughout the Lake of the Woods.

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006. Geology of the Monument Bay Area, Lake of the Woods, District of Kenora

M.G. Morrice[1] and G.A. MacMaster[2]

[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Geological Assistant, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

Little was known about the geology and mineral potential of the Monument Bay area prior to 1986; only parts of the area had been mapped previously (Lawson 1885; Greer 1931). Field investigations were initiated in 1986 and continued in 1987 in order to significantly increase the geological data base and enhance interest in the mineral potential of the area. Significant new gold assays were returned from grab samples collected by the field crew during the 1987 field season.

During the 1987 field season, an area of 150 km was mapped at a scale of 1:15 840. This area is bounded by Latitudes 49°22′N and 49°30′N and Longitudes 94°56′W and 94°47.7′W. The Town of Kenora is 50 km northwest of the centre of the map area. Access to the map area is by boat from either Kenora or Angle Inlet, Minnesota, 20 km southwest of the map area.

MINERAL EXPLORATION

The following information has been obtained from the assessment files of the Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kenora.

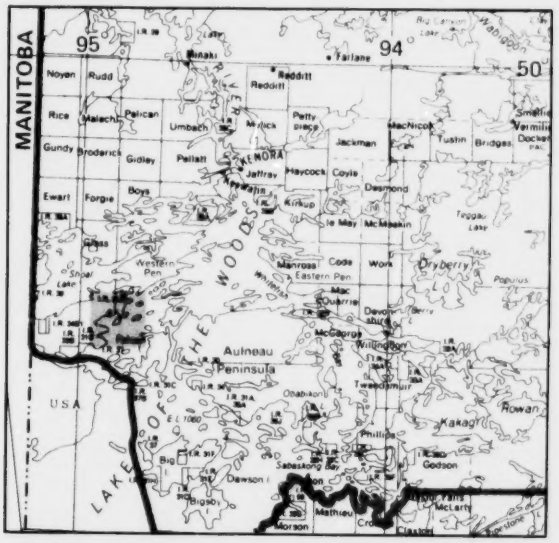
Exploration for base-metal mineralization (zinc and copper) was carried out in 1975 by Hudson Bay Exploration and Development Company Limited (HBED) in the western part of the map area, and by Phelps Dodge Corporation in the northern part of the map area. Both companies appear to have been following up airborne geophysical surveys that are not on file. HBED reported results from two drillholes and Phelps Dodge Corporation reported results from one drillhole.

GENERAL GEOLOGY

Parts of the present map area are included in maps produced by Lawson (1885) and Greer (1931). The map area (Figure 006.1) adjoins the Western Peninsula area, mapped by Davies (1983) to the north, and the Northwest Angle Inlet area (Morrice MacMaster 1987) to the west.

With the exception of the northwest-trending Early Proterozoic diabase dikes, all bedrock in the map area is inferred to be Archean in age.

Supracrustal rocks in the Monument Bay map area are mainly metavolcanics which range in composition from ultramafic to felsic. Metasediments underlie about 5% of the map area. On the basis of field observations and geochemical data from the adjoining Northwest Angle Inlet map area, two readily distinguishable, geochemically distinct volcanic suites are recognized. An alkalic (shoshonitic) suite



LOCATION MAP

Scale : 1:1 584 000 or
1 inch to 25 miles

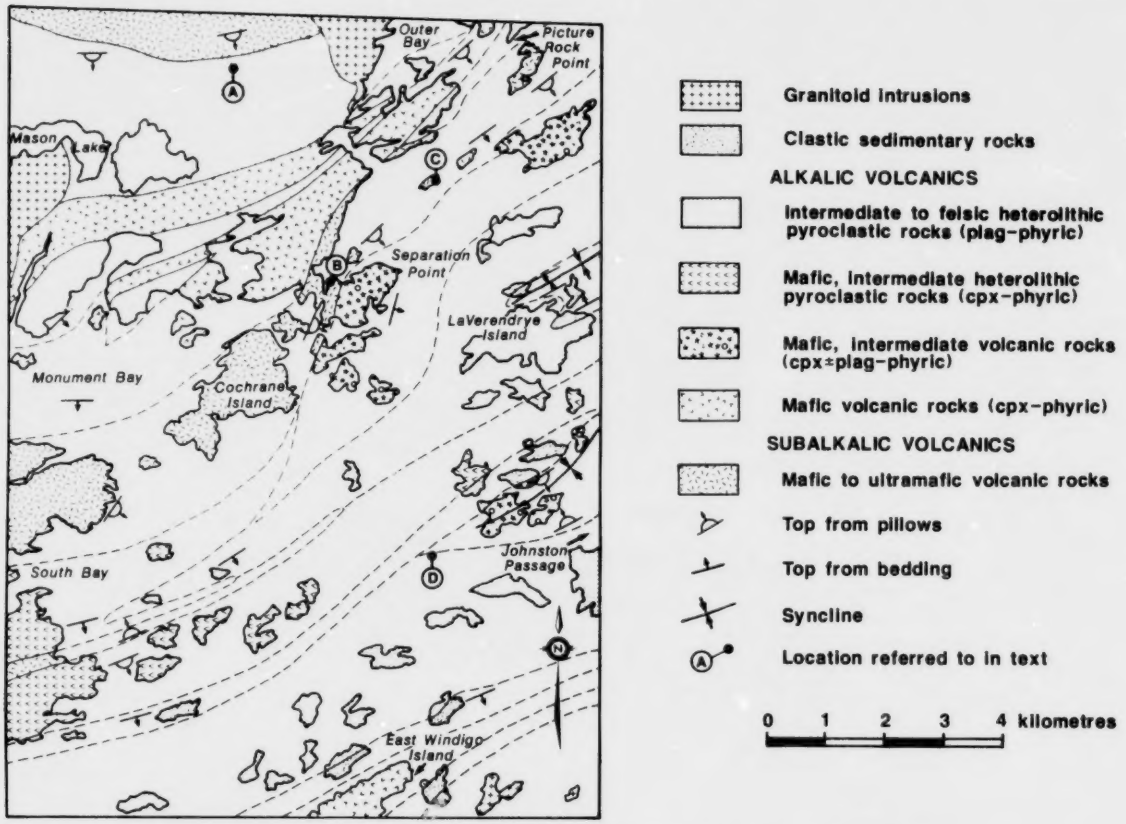


Figure 006.1. *Generalized geological map of the Monument Bay Area, District of Kenora.*

composes about 80% of the metavolcanics and ranges in composition from mafic to felsic. The remaining metavolcanics are subalkalic basaltic komatiites and basalts (Figure 006.1).

Alkalic rocks are predominantly pyroclastic in nature and of basaltic composition. Individual clasts are commonly highly amygdaloidal and characteristically contain euhedral calcic clinopyroxene phenocrysts (now largely amphibole). Subalkalic basalts are invariably pillowed or massive flows, are non to weakly vesicular, aphyric and commonly variolitic.

The distinct megascopic volcanic features can be related to differences in the geochemistry. Alkalic basalts (SiO_2 <53%) have high K_2O contents (K_2O <1%) (Figure 006.2) and Light Rare Earth Elements (LREE) enriched patterns ((La/Yb)N >6) (Figure 006.3). The subalkalic basalts are low in K_2O (K_2O <0.3%) and have flat to slightly LREE depleted patterns ((La/Yb)N <1.7) (Figure 006.3).

The alkalic intermediate metavolcanics are characterized by the presence of slender, bladed, plagioclase phenocrysts up to 1.5 cm long. The alkalic felsic metavolcanics lack any characteristic textural features to distinguish them from the more widespread subalkalic felsic metavolcanics which occur elsewhere in the Superior Province. However, in the Monument Bay and Northwest Angle Inlet map areas, there is a close association between plagioclase-phyric and quartz-phyric felsic metavolcanics and the texturally distinct alkalic mafic and intermediate metavolcanics. Preliminary geochemical data indicate a trend of decreasing K_2O with increasing SiO_2, which mimics the trend for an Archean shoshonitic association at Oxford Lake, Manitoba (Brooks *et al.* 1982). For these reasons, the intermediate and felsic metavolcanics of the Monument Bay map area are considered to be evolved members of an alkalic (shoshonitic) association.

The alkalic and subalkalic metavolcanics are interlayered and appear to form a conformable sequence.

SUBALKALIC METAVOLCANICS

Subalkalic mafic and ultramafic metavolcanics occur in two discrete horizons within the map area (Figure 006.1). The first horizon, represented by the Cochrane Island formation, ranges in thickness from 0.6 to 2.8 km and trends northeasterly across the map area through Cochrane Island. This unit continues northeast into the Western Peninsula area (Davies 1983) and the Chisholm Island map area (Ayer *et al.*, Article 004., this volume). A second horizon of subalkalic metavolcanics, up to 300 m thick, trends east-northeasterly across the southern part of the map area. Several other thin horizons of subalkalic basalts and

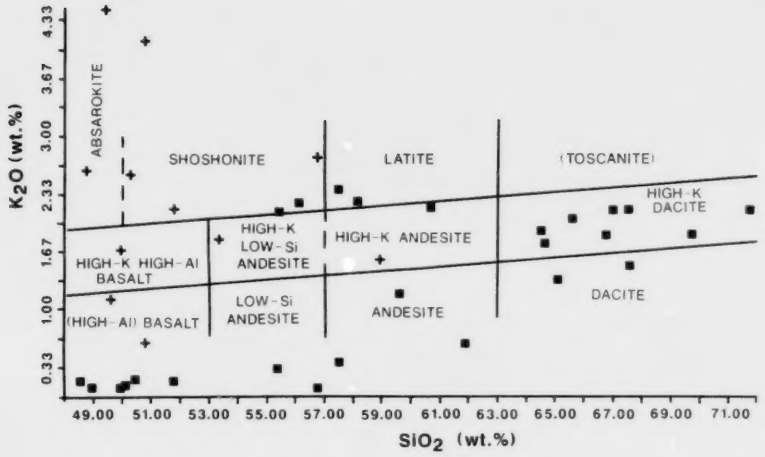


Figure 006.2. *K_2O versus SiO_2 (weight %) for metavolcanics of the Northwest Angle Inlet Area. (*) denotes clinopyroxene-phyric volcanics; remainder are aphyric or plagioclase-phyric. Field boundaries after Mackenzie and Chapple (1972).*

basaltic komatiites occur in the southern half of the map area.

Mafic metavolcanics comprised of 40 to 70% black amphibole, and ultramafic metavolcanics comprised of 60 to 95% green amphibole, occur as non to sparsely vesicular, aphyric variolitic flows. Individual flows are 5 to 25 m thick and are characterized by a coarse-grained or pyroxene-spinifex textured, massive mafic base, and a fine-grained, pillowed ultramafic top. This intimate association of basaltic and basaltic komatiitic liquids may be analogous to mixed komatiitic lavas from Munro Township (Arndt and Nesbitt 1984).

Minor, but conspicuous, equant plagioclase phenocrysts, up to 1 cm in diameter, are present in a) subalkalic flows (leopard rock) in the extreme northern part of the map area; b) in the Cochrane Island formation in the Northwest Angle Inlet map area; and c) in a subalkalic flow interlayered with alkalic pyroclastics southwest of Separation Point. The presence of these plagioclase phyric rocks interlayered with alkalic metavolcanics indicates that they are not restricted to the lower mafic sequence in the Lake of the Woods area (cf. Ayer and Sweeny 1986; Ayer and Gil 1986; Ayer *et al.* 1985).

Thinly bedded siltstones and argillites are interbedded with subalkalic flows. They are common near the top of the Cochrane Island formation, north of Separation Point.

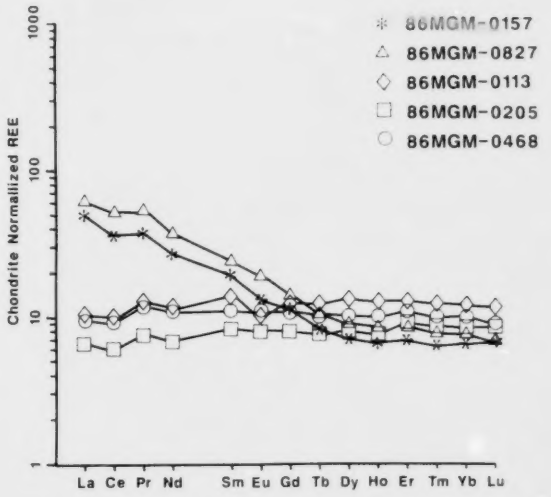


Figure 006.3. *REE diagram for Mafic and ultramafic volcanics of the Northwest Angle Inlet Area. 157, 827-clinopyroxene-phyric alkalic basalts; 113-aphyric subalkalic basalt (Cochrane Island formation); 468-plagioclase-phyric (leopard rock) subalkalic basalt (Calm Bay, Shoal Lake); 205-subalkalic basaltic komatiite.*

ALKALIC METAVOLCANICS

Alkalic metavolcanics range in composition from mafic to felsic. Mafic and intermediate varieties predominate in the central part of the map area while intermediate and felsic metavolcanics are common in the northern and southern parts of the map area.

Alkalic mafic metavolcanics occur in five distinct units within the map area: north of Monument Bay, Monument Bay, Separation Point, South Bay and East Windigo Island (Figure 006.1). All are characterized by the presence of 0.2 to 1 cm calcic clinopyroxene phenocrysts (now largely amphibole), and amygdaloidal flows and clasts.

North of Monument Bay, a laterally persistent horizon of clinopyroxene-phyric amygdaloidal, pillowed basalt has been traced for 12 km along strike, decreasing in thickness from 1 km in the Northwest Angle Inlet area (Morrice and MacMaster 1987) to 30 m near Picture Rock Point. This unit contains 10 to 25% clinopyroxene phenocrysts, now largely flattened and replaced by biotite, and 5 to 40% calcite-filled amygdules. Pillows are up to 2 to 3 m in diameter and selvages are 3 to 5 cm thick.

The Monument Bay, Separation Point, and East Windigo Island mafic units are composed dominantly of clinopyroxene-bearing mafic and intermediate tuff-breccia, lapilli-tuff and tuff, and lesser amounts of

pillowed and massive flows. All three units are characterized by monolithic pyroclastics containing abundant scoria clasts. Bomb sags and coarse and diffusely bedded tuffs suggest that the rocks were deposited in a proximal shallow water or subaerial environment. Little or no evidence for reworking was noted. Many of the Separation Point metavolcanics contain 5 to 30% bladed plagioclase phenocrysts up to 0.3 by 1.5 cm.

Alkalic mafic metavolcanics in the South Bay area are predominantly clinopyroxene-phyric heterolithic pyroclastics that are interbedded with subalkalic mafic and intermediate flows. The alkalic rocks are well bedded debris flows with less than 1 m to several metre thick beds that consist of varying proportions of mafic and intermediate clasts.

Alkalic intermediate metavolcanics occur as plagioclase-phyric pillowed flows in the Separation Point and Johnson Passage areas, and as plagioclase-phyric clasts in heterolithic intermediate-felsic pyroclastics in the La Verendrye Island and Drift Island areas. These latter occurrences are discussed in the section on felsic metavolcanics.

Intermediate pillowed flow units are distinct, being composed of 10 to 25%, 2 to 5 mm long, bladed plagioclase phenocrysts in a light grey groundmass with 10 to 25% amygdules. Pillows are 1/2 to 1 m in diameter and are characterized by 2 to 5 mm thick selvages. Abundant pillow breccias are associated with these intermediate pillowed rocks.

Intermediate-felsic metavolcanics underlie much of the northern and southern part of the map area. Heterolithic pyroclastics predominate, and synvolcanic sills are abundant in the southern part of the map area. Clasts with 5 to 30%, 1 to 3 mm equant-shaped plagioclase phenocrysts and aphyric felsic clasts are common in the felsic pyroclastics north of Monument Bay and in those of the southern part of the map area. Felsic clasts found within the intermediate-felsic pyroclastics centred on La Verendrye Islands are aphyric. Quartz-plagioclase phyric clasts occur as discrete horizons within the northern and southern units. Individual deposits are poorly sorted, clast supported, and thickly bedded. They are interpreted to have been deposited as debris flows.

METASEDIMENTS

Three types of metasediments occur in the map area. In the Outer Bay area, local reworking of heterolithic debris flows has produced conglomerate. Thinly-bedded argillaceous interflow metasediments are found interbedded with the flows in the Cochrane Island formation. The most common and widespread metasediments are wacke and arenite, with lesser amounts of magnetite ironstone that are associated with intermediate-felsic metavolcanics in the southern half of the map area. Five discrete wacke units are recognized; however, the possibility of repetition due to folding or faulting cannot be ruled out. Bedding thickness in the quartz-plagioclase wackes varies from <1 cm to 1.5 m and AE Bouma sequences are common. Morphologically, these resemble the Warclub Group wackes found on the eastern side of Lake of the Woods (Glen Johns, Geologist, Precambrian Geology Section, Ontario Geological Survey, Personal Communication, 1987).

INTRUSIVE ROCKS

Metamorphosed, synvolcanic, <1 to 40 m wide, intermediate, felsic plagioclase and quartz-plagioclase porphyry sills occur throughout the map area. Synvolcanic metamorphosed mafic sills and dikes are confined to the northern subalkalic unit.

Three late tectonic granitoid plutons intrude the supracrustal rocks of the Monument Bay area. In the north, the Mason Lake and Outer Bay plutons are medium- to coarse-grained, inequigranular, to microcline megacrystic hornblende granodiorites. A weak foliation occurs within these granodiorites along and parallel to their margins. In the southeastern part of the map area, a strongly foliated microcline phyric hornblende syenite intrudes intermediate-felsic metavolcanics and metasediments. The syenite has a pronounced igneous foliation defined by the alignment of tabular microcline phenocrysts.

Foliated and massive biotite-bearing lamprophyre dikes occur throughout the map area, with their greatest concentration being within and adjacent to the Cochrane Island formation. Several of these lamprophyres are associated with chaotically brecciated country rock that has been interpreted to be the result of hydrofracturing.

Early Proterozoic northwest-trending diabase dikes <1 to 20 m wide, are a minor constituent of the map area. They are aphanitic to medium grained and have well defined chill margins.

STRUCTURE AND METAMORPHISM

Reliable facing indicators are unevenly distributed throughout the map area. This has greatly hindered interpretation of the structure. The general trend is of south to southeasterly facing directions with some, possibly minor, reversals. The most noteworthy reversals in top directions define a synclinal keel in the metasediments north of La Verendrye Island and a syncline west of Johnston Passage where the intermediate metavolcanics overlie wackes. In the southern part of the map area, this apparent cyclic sequence of intermediate to felsic pyroclastics overlying the metasediments may be a result of repetition through folding and/or faulting.

The supracrustal lithologies in the map area have a well developed foliation; however, the intensity is quite variable. The most intense foliation occurs in a 50 to 500 m wide zone of sporadic, often intense, carbonatization which trends northeasterly through the northern part of the map area. This high strain zone may link up with the Monument Bay Fault Zone to the west (Morrice and MacMaster 1987). Kinematic indicators suggest that this is a zone of flattening (pure shear) with a minor late, subhorizontal, predominantly dextral, component of simple shear. Minor quartz veins that may or may not contain ankerite and pyrite occur within thin, 1/2 to 2 m wide 080° trending shear zones within this zone of intense flattening.

In the Monument Bay area, foliations have a 20 to 30° dip to the south. In the southern part of the

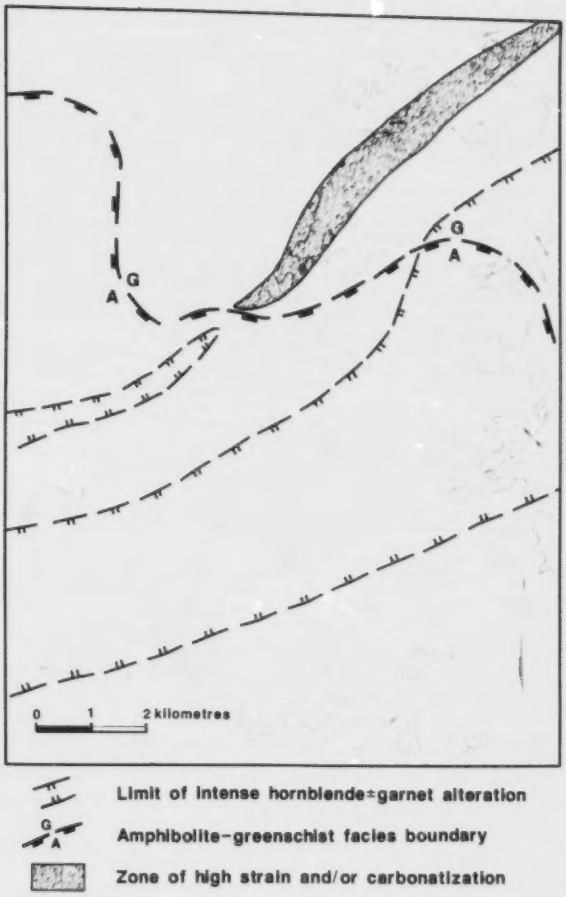


Figure 006.4. *Location of amphibolite-greenschist facies boundary and major zones of amphibolite (± garnet) and carbonate alteration in the Monument Bay Area.*

map area, foliations have a shallow dip to the north. A fanning array to the foliation is seen between these two extremes. Dips are steeper to the south in the eastern part of the map area.

Deformation within the southern part of the map area is marked initially by the development of conjugate 070° and 110° trending shear fractures which are bisected by the regional 090° foliation. As regional flattening proceeds, these fractures gradually converge until parallel. In local areas, minor subhorizontal sinistral movement has been initiated in shear zones parallel to the 070° fracture set.

Amphibolite facies mineral assemblages characterize lithologies in most of the map area with the amphibolite-greenschist transition boundary trending approximately northwest across the northeastern part of the map area (Figure 006.4). Within pelitic metasediments, cordierite and garnet are ubiquitous, and staurolite and andalusite occur in the vicinity of Johnson Passage. Pelitic metasediments have a migmatitic texture in the southeastern part of the map area. Intense recrystallization of the felsic metavolcanics in the southern part of the map area may be related to their proximity to the Sabaskong Batholith. Epidote-hornblende hornfels contact aureoles have developed in the country rock adjacent to granitoid plutons and diabase dikes.

ALTERATION

Two alteration mineral assemblages are widespread in the Monument Bay area: chlorite ± carbonate alteration in greenschist facies rocks, and hornblende ± garnet ± carbonate alteration within amphibolite facies metavolcanics (Figure 006.1). The two assemblages may represent equivalent alterations with their contrasting mineralogy being the result of metamorphism under different pressure/temperature conditions (cf. Andrews *et al.* 1986). Chlorite ± carbonate alteration is most intense northeast of Cochrane Island within the high strain zone which has affected both the alkalic and subalkalic metavolcanics. Hornblende ± garnet alteration has affected most lithologic units in the map area and is well developed in a 2.5 km wide northeast-trending zone transecting the central part of the map area (Figure 006.4). Within this zone, alteration varies greatly from being intense and pervasive to minor and fracture controlled.

ECONOMIC GEOLOGY

While there are no known mineral occurrences in the Monument Bay map area, there are several features of the geology which are attractive in terms of gold potential and, to a lesser extent, base metal exploration.

Base metal (zinc, copper) exploration should focus on the felsic metavolcanics west of Outer Bay. Here, monolithic to heterolithic quartz-plagioclase-phyric pyroclastics contain pyrrhotite clasts that are up to about 4 cm in size.

Gold exploration should be directed primarily to two areas: the shear zones within subalkalic flows of the Cochrane Island formation west and north of Separation Point, and the region of extensive hornblende ± garnet alteration. The amphibolite-greenschist facies transition boundary crosses both areas at near right angles and should be the focus of initial exploration. Seven grab samples collected from shear zones in the Cochrane Island formation, in the bay north of Separation Point, by members of the field party, were assayed by the Geoscience Laboratory, Ontario Geological Survey, and were found to contain >100 ppb gold; two of these (locations A and B, Figure 006.1) contain 52 ppm gold (1.5 ounce gold per ton) and 870 ppb gold, respectively.

Sulphide mineralization occur in discrete zones within hornblende ± garnet altered intermediate + felsic metavolcanics west of Johnston Passage (e.g. location D, Figure 006.1). This alteration associated mineralization should be explored, especially to the northeast across the amphibolite-greenschist facies transition boundary.

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007. Geology of the Rainy River Area, District of Rainy River

G.W. Johns

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Rainy River area, once considered to be predominately covered by Quaternary deposits, has been largely unexamined for mineral potential. A Quaternary geological survey carried out by A.F. Bajc in the summer of 1986 (Bajc and Gray 1987) noted a significant amount of out-crop of Archean supracrustal rocks. A reconnaissance geological survey completed on this 1700 km^2 area significantly added to the existing data base by outlining previously unknown volcanic stratigraphy and re-evaluating the mineral potential.

The area is bounded by Rainy River to the south, Latitude 49°00'N to the north, Lake of the Woods to the west and Longitude 94°00'W to the east. The Town of Rainy River is in the southwestern portion of the area. Excellent access to the map area is provided by a grid network of roads that include provincial highways 600, 617, 618, 621 and interconnecting township and concession roads.

MINERAL EXPLORATION

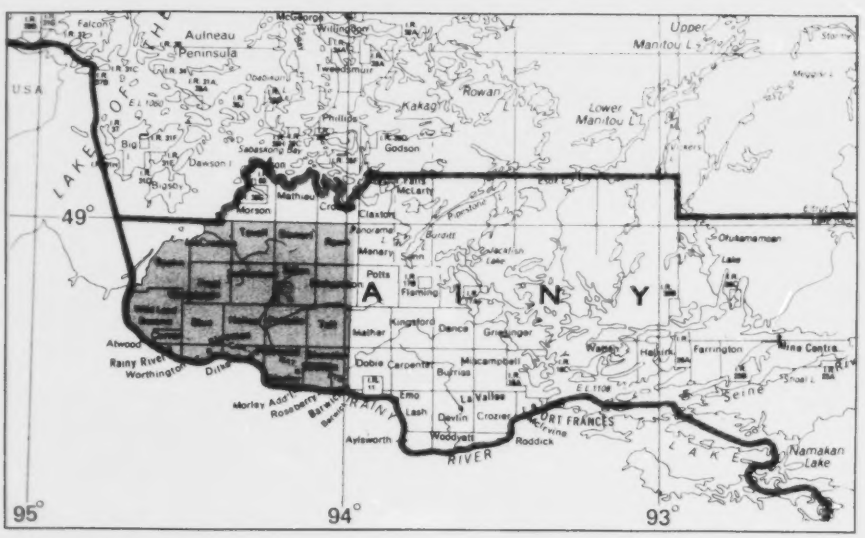
The area west of the Dobie Stock, north of Barwick, was tested for potential nickel and copper by Falconbridge Nickel Mines Limited in 1953 (Fletcher and Irvine 1955). The author was informed by local land owners of prospecting and minor exploration for gold by an American consortium within the past 10 to 15 years.

A sulphide occurrence in the northern half of lot 8, concession II, of Sutherland Township was prospected for base metals by trenching (Assessment Files, Resident Geologist's Office, Ministry of Northern Development and Mines, Kenora). In 1956, Stratmat Limited completed a geological and magnetic survey and diamond drilled ten holes for a total of 1550 feet on this sulphide occurrence. Sulphides consisted of pyrite and pyrrhotite in massive and disseminated bands parallel to foliation in a gneissose metavolcanic. Samples submitted by the company for spectrographic analysis contained traces of Cr, Co, Cu, Mn, Mo, Ni, Ti, V, Zn, and Zr.

GENERAL GEOLOGY

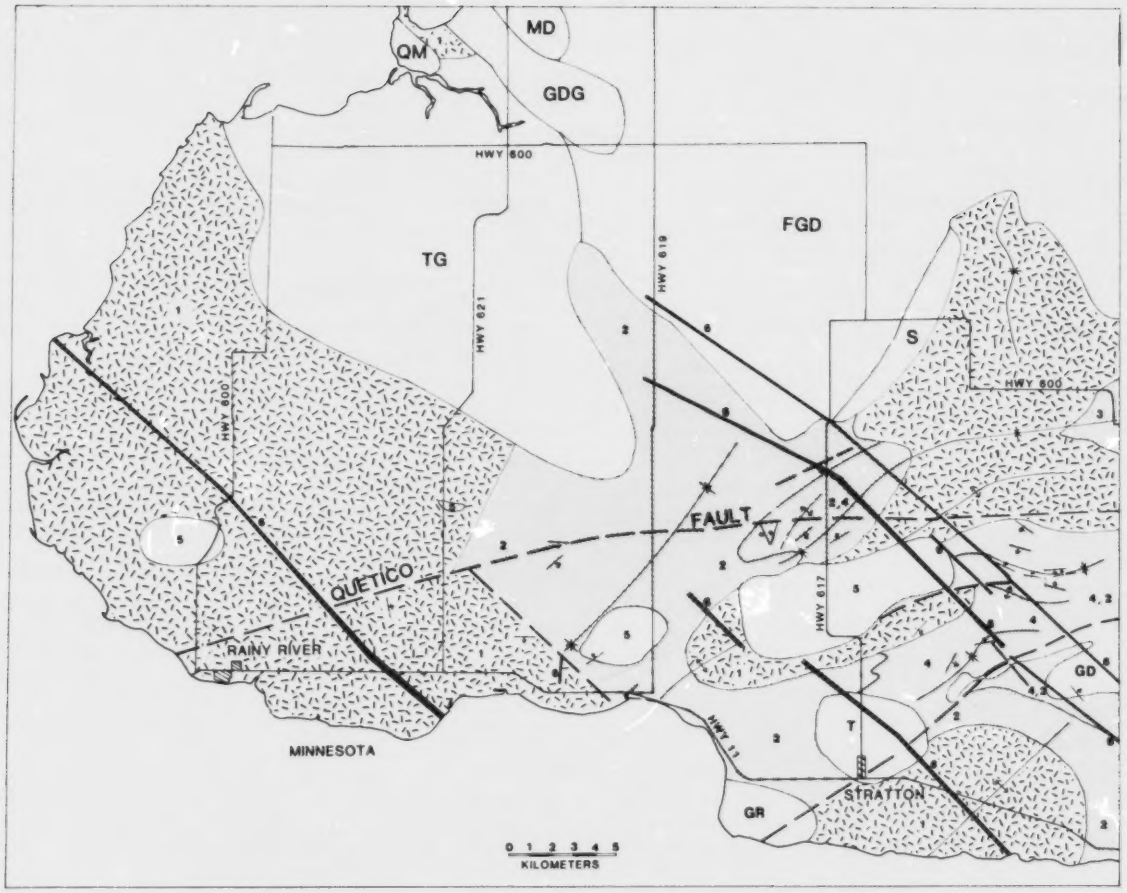
Previous geological mapping in the map area was carried out in the nineteenth century by A.C. Lawson (1888). The Emo area to the east as well as part of the current map sheet were mapped in 1953 by Fletcher and Irvine (1955). C.E. Blackburn mapped the Off Lake-Burditt Lake area to the northeast which includes part of the current map area (Blackburn 1976). A.F. Bajc completed a Quaternary geology study of the area in 1986 (Bajc and Gray 1987).

Except for northwest-trending Proterozoic diabase dikes, the map area is underlain by Archean supracrustal and granitoid rocks. The northern one-third of the area is underlain by foliated tonalite and granodiorite, tonalitic gneiss, and massive monzodiorite phases of the Sabaskong Batholith. This batholith intruded supracrustal rocks of the Wabigoon Subprovince exposed in the southern two-thirds of the map area. These volcanic and sedimentary rocks have been metamorphosed to low- to mid-amphibolite facies. Contact metamorphism of internal stocks have locally increased the metamorphic grade to upper amphibolite and in some cases, has resulted in partial melting of the host rocks.



LOCATION MAP

Scale : 1:1 584 000 or 1 inch to 25 miles



1 mafic massive and pillowed flows, pillow breccia, hyaloclastite
2 mafic to intermediate hornblende phyric debris flows and pyroclastics: intermediate pyroclastics
3 quartz feldspar porphyry
4 wacke, reworked tuff
5 post tectonic stock
6 diabase
upper diverse unit
lower mafic unit

FGD foliated granodiorite
GDG granodiorite gneiss
GD granodiorite
GR granitoid rocks
MD monzodiorite
TG tonalite gneiss
S syenite
T tonalite
QM Quartz Monzonite

anticline
syncline
strike and younging direction of stratigraphy
fault
lithologic and stratigraphic contact
town

Figure 007.1. *Geology and stratigraphy of the Rainy River-Stratton Area, District of Rainy River.*

The supracrustal rocks can be subdivided into two stratigraphic units (Figure 007.1) similar to the subdivision proposed for the rest of the Wabigoon Subprovince (c.f. Johns and Thurston 1987; Johns *et al.* 1986). A lowermost mafic unit consisting of massive and pillowed mafic flows, with local horizons of pillow breccia to hyaloclastite, and feldspar phyric flows, is found in the western, northeastern, and southeastern portions of the map area. Conformably overlying this lower mafic unit is an upper diverse unit comprised of interbedded and interdigitated mafic and intermediate debris flows and intermediate pyroclastics, wacke and reworked tuff.

Mafic metavolcanic flows are restricted to the lower mafic unit (Figure 007.1). Fine- to medium-grained flows and pillowed flows predominate with minor pillow breccia to hyaloclastite and feldspar phyric flows (leopard rock). Medium- to coarse-grained gabbros crosscut the mafic flows. An aeromagnetic high in the vicinity of Sleeman, 10 km east of Rainy River, may reflect the presence of a covered mafic intrusive body. All the mafic rocks are dark green on both the fresh and weathered surface. The mafic rocks are well foliated and, in the vicinity of the granitoid intrusions, become gneissose and develop abundant garnet. (*see* Blackburn (1976) for a

description of the mafic units occurring in the northeast part of the map area).

Overlying the lower most mafic unit is a complex sequence of debris flows, reworked tuffs, sediments, and intermediate pyroclastics belonging to the upper diverse unit. Heterolithic debris flows consist of both mafic and intermediate subrounded, mafic phenocryst-bearing clasts set in a mafic, phenoclast-bearing tuffaceous matrix. These massive, ungraded debris flows range in size and sorting from lapilli-tuff to tuff-breccia and have been noted in the upper diverse units in other parts of Lake of the Woods (M.G. Morrice and J.A. Ayer, Geologists, Precambrian Geology Section, Ontario Geological Survey, Personal Communication, 1987; Trowell 1986). Interbedded with the debris flows are minor monolithic, phyric, mafic pyroclastics. The mafic phenocrysts and phenoclasts, which are hornblende, were originally clinopyroxene (M.G. Morrice, Geologist, Precambrian Geology Section, Ontario Geological Survey, Personal Communication, 1987). This unit can be traced northeastward where it is found in contact with the Sabaskong Batholith. Interdigitated with the mafic debris flows to the east and east-northeast are interbedded intermediate tuff and sedimentary rocks In general, the tuffs grade easterly into reworked tuff and wacke. Very little coarse intermediate pyroclastic rocks were noted within the map area.

Intermediate to felsic granitoid stocks are totally enclosed by the supracrustal assemblage (Figure 007.1). The stocks that trend northeast in the southeastern corner of the area are foliated biotite-hornblende tonalite and trondhjemite, and hornblende granodiorite that have complex contact relationships with the surrounding supracrustals. They are fine to medium grained and the foliation is defined by the alignment of the mafic minerals. Posttectonic stocks having sharp contacts with the supracrustal rocks are medium to coarse grained, and are massive to primary flow foliated with all tabular minerals showing alignment. The easternmost oblong-shaped stock north of Stratton is a plagioclase-phyric, coarse-grained hornblende tonalite with variable amounts of biotite.

The smaller, rounded stock to the west is zoned with potassium feldspar-phyric hornblende granodiorite surrounded by a complex diorite border zone. Within this complex diorite border zone, a complete gradation can be observed from mafic volcanic xenoliths, partially digested xenoliths, remnant, wispy appearing xenoliths to massive diorite. The massive diorite contains minor potassium feldspar phenocrysts and patches of hornblende. Aplite and pegmatite represent the youngest phase. The border zone is a mafic volcanic xenolith-bearing diorite that resulted from the partial melting of the host rock and mixing with the parental magma (c.f. Edwards 1982).

A small stock in the western portion of the area is a massive, coarse-grained, biotite hornblende tonalite. It is exposed only in one out-crop area and its true extent is not known.

The Sabaskong Batholith occupies the northern third of the map area and consists of several phases. The western lobe is a gneissose biotite-hornblende tonalite intruded by granodiorite dikes. The eastern lobe is a foliated granodiorite with variable percentages of hornblende and biotite with aplite and pegmatite dikes. In the extreme northwest massive, flow foliated, coarse-grained, hornblende monzodiorite intrudes a grey, fine-grained, highly contorted, banded, biotite granodiorite gneiss. In the same area a foliated biotite quartz monzonite out-crops. Hornblende syenite is found between the foliated granodiorite and the mafic metavolcanics in the northeast (Blackburn 1976). All phases of the batholith contain xenoliths of mafic volcanics.

Northwest-trending dikes of quartz diabase intrude all rock types. The dikes range up to 100 m in thickness but smaller dikes as thin as a few centimetres were noted. Fine-grained margins give way to medium- to coarse-grained centres. Several out-crops have cross cutting diklets of more felsic material possibly representing a late granophyric differentiate. All the dikes appear fresh and have a distinctive brown weathered surface.

STRUCTURAL GEOLOGY

The general trend of the volcanic rocks is northeastward which is consistent with the trend of the supracrustal rocks in the Off Lake-Burditt Lake area (Blackburn 1976).

All of the supracrustal rocks and the granitoid rocks of the Sabaskong Batholith are foliated to schistose. Near the supracrustal-batholith contact, foliations strike subparallel to the contact. Away from the contact, foliation trends vary between northeast and east. Bedding within the upper diverse unit also ranges between northeast and east. Dips for both foliation and bedding are generally vertical to steep in a southerly direction.

Blackburn (1980) has interpreted the Quetico Fault to strike westerly to southwesterly. The present survey has found no evidence on the ground to place the location of the Quetico Fault accurately, and the interpretation of Blackburn (1980) is retained. A northeast-trending fault is interpreted in the southeastern part of the area. This interpretation is based on evidence presented by Fletcher and Irvine (1955, p.19) and a lineament in Minnesota (Ojakangas *et al.* 1977). This fault appears to be a splay from the Quetico Fault. An east-northeast-trending fault in the east-central part of the map (Figure 007.1) has been interpreted to explain the removal of the northern limb of an anticlinal structure.

Folding based on top reversals and stratigraphic interpretation (Figure 007.1) is complex. Except for the northeastern part of the map area, the fold axes trend northeast curving towards the east. This folding accounts for the complex map pattern for the upper diverse unit.

MINERAL POTENTIAL

GOLD

The potential for gold mineralization is higher in the eastern half of the map area where the metamorphic grade is slightly lower than in the west. There is potential for gold mineralization along the Quetico Fault. As the fault trace cannot be documented with

accuracy, basal till prospecting is recommended in the down-ice direction from the fault.

BASE METALS

Ojakangas *et al.* (1977, p.65) noted high base metal values in the Ab, B, and C soil horizons just south of the eastern end of the map area in Minnesota. As glacial cover is thick in this area, the anomalies may be due to sulphide-bearing debris in the glacial deposits. As the ice direction is 220° in this area, that region of Canada up ice from this locality should be checked for base metals.

BUILDING STONE

The small posttectonic stock in the south-central part of the area is massive and has few widely spaced joints. This may have economic potential for dimension stone.

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008. The Queen Island Conglomerate, Lake of the Woods, District of Kenora

G.W. Johns

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

A conglomerate of problematic origin occurs in the vicinity of Queen Island on Lake of the Woods, 24 km south-southeast of the Town of Kenora. Car (1980) and Davies (1983) originally mapped these rocks as "granodiorite-clast conglomerate" while Ayer and Gil (1986) mapped them as conglomerate and proposed that they may represent "peculiarly brecciated intrusions".

The author of this summary report studied these problematic rocks as part of his regional geological investigations in the Western Wabigoon Subprovince. The results of this study will help in reaching a better understanding of the regional paleoenvironment, which in turn will aid in evaluating the mineral potential of the area.

GENERAL GEOLOGY

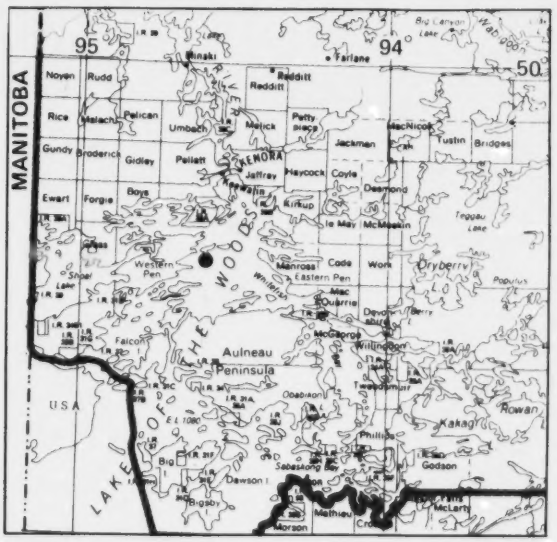
The Lake of the Woods greenstone belt can be subdivided into a Lower Mafic unit and an overlying Upper Diverse unit. The Upper Diverse unit is composed of interbedded mafic metavolcanics, intermediate to felsic metavolcanics, and metasediments. In the vicinity of Crow Rock Island and Queen Island, the conglomerate lenses occur within the regionally south-facing Upper Diverse unit as slightly discordant horizons within the pyroclastics and heterolithic intermediate tuff-breccia that are interpreted as debris flows (Ayer and Gil 1986). The three conglomerate lenses have been designated the northern, central, and southern conglomerates (John Ayer, Geologist, Ontario Geological Survey, personal communication, 1987).

DESCRIPTION OF THE CONGLOMERATE

The northern conglomerate unit was subdivided by Ayer and Gil (1986) into monolithic and heterolithic portions. Car (1980), as part of a broader study of the volcanic and sedimentary rocks in the area, undertook thin section examination of clasts of the monolithic conglomerate. The central and southern conglomerate units are monolithic in nature composed of similar granodioritic clasts.

The northern conglomerate (Ayer and Gil 1986) was examined in this study. It contains well-preserved sedimentary features while the other two conglomerate units are deformed and sedimentary features are not well preserved. The study of the lensoidal conglomerate unit was restricted to well-exposed shoreline outcrops on islands west of Little Crow Rock Island north of Queen Island. On the map, the occurrence of the conglomerate unit is lensoidal in shape and about 1 by 2.9 km in size.

Within the north-facing unit of granodiorite-bearing material, a tripartite stratigraphy (Figure 008.1) was recognized. Although an accurate thickness for each part of the stratigraphy cannot be obtained due to exposure being limited to scattered islands, estimated thicknesses are: unit A—100 to 200 m, unit B—40 to 60 m, and unit C—80 to 100 m. The base of the conglomerate unit is conformable with underlying heterolithic, volcaniclastic debris flows that contain no granodioritic clasts. The lowermost succession ('A') is interpreted as heterolithic, volcaniclastic debris flows containing minor, rounded granodiorite clasts that increase in abundance upward. Overlying, with a sharp, conformable contact, is



LOCATION MAP

Scale : 1:1 584 000 or
1 inch to 25 miles

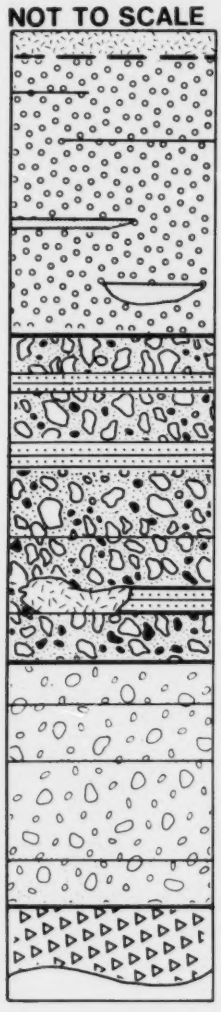


Figure 008.1. *Schematic columnar section of the northern conglomerate found west of Little Crow Rock Island, Lake of the Woods.*

a mafic flow bearing succession ('B') of bedded, heterolithic, granodiorite clast-bearing debris flows with quartz-feldspar wacke tops which in turn is capped by a coarsening upward, poorly bedded, monolithic, granodiorite conglomerate ('C'), again interpreted as debris flow. The top of the conglomerate, where exposed, is in fault contact with mafic metavolcanics.

The heterolithic, volcaniclastic debris flows of the lower-most succession ('A') are thickly bedded with fine-grained, graded, wacke tops. Bedding contacts are both gradational and sharp. Ten to forty centimetre subangular to subrounded irregular-shaped clasts of plagioclase-phyric andesite, quartz porphyry, quartz-feldspar porphyry, intermediate volcanic rocks, feldspar-phyric intermediate volcanic rocks, and round to subround, elongate to spherical-shaped granodiorite are supported in a fine-grained, immature, quartz-feldspar tuffaceous matrix. The debris flows have the size and sorting characteristics of tuff-breccia.

Conformably overlying the lower-most succession ('A'), with a sharp contact, are thin to thick bedded, heterolithic, volcaniclastic debris flows ('B') that have minor interbedded mafic hyaloclastite and flows. As well as the volcanic detritus found in the underlying debris flows ('A'), these beds contain angular mafic volcanic fragments. Rounded granodiorite clasts in the pebble to cobble size range are abundant. The debris flows are well bedded exhibiting both reverse and normal grading in the massive portion and normal grading in the tuffaceous laminated interbeds. The clasts are supported in an immature, angular, chloritic, quartz-feldspar tuffaceous, matrix. Beds increase in thickness with stratigraphic height.

The mafic flows and hyaloclastite within the debris flows are limited in size, ranging up to 3 m wide and 1 m thick. The base of the mafic flows and hyaloclastite have incorporated material from the underlying debris flows, whereas the upper contact is erosional. One exposed mafic horizon is composed entirely of hyaloclastite and another is massive and

fine grained with minor hyaloclastite margins. The mafic clasts found in the debris flows ('B') are angular, pillow fragments, hyaloclastite fragments, and massive flow fragments. The very angular nature to the clasts indicates that a minimum of reworking and transportation took place, and hence are interpreted to be eroded directly from the interbedded mafic units. The percentage of mafic clasts within the debris flows decreases up-section.

Overlying the mafic clast-bearing middle succession with a sharp conformable contact is the uppermost succession ('C') composed of monolithic granodiorite conglomerate. This coarsening upward succession of poorly sorted conglomerate is thickly (>2 m) bedded with discontinuous, thin, fine-grained, laminated, normally graded, sandy bed tops. Other beds are outlined by horizons that contain more matrix and smaller clasts than the main mass of the bed. The clasts are subround to round ranging in size from less than 1 cm to greater than 1 m, with the majority being in the range of 10 to 40 cm. The largest clast noted is greater than 3 m. Larger clasts occupy distinct horizons within some of the thicker conglomerate beds. These clasts are supported by an immature, medium-grained, well sorted, quartz-feldspar arenite matrix that is the same composition as the clasts. The matrix within individual beds grades between chlorite and non-chlorite bearing, with the chloritic portions being finer grained and quartz rich in comparison with the non-chloritic matrix. The chlorite-bearing matrix may be the result of selective alteration of the matrix.

DISCUSSION OF THE DEPOSITIONAL ENVIRONMENT

The monolithic conglomerate is believed to have formed by erosion from a large subaerial volcanic dome complex (Car 1980). A large dome complex would cool slowly, accounting for the medium-grained crystalline nature of the granodiorite clasts. The dome complex would act as a point source for the monolithic conglomerate, effectively blocking the supply of other volcanic detritus to the conglomerate (Car 1980). The debris flows underlying the monolithic conglomerate are heterolithic volcaniclastics that contain an increasing component of granodiorite clasts as stratigraphic height increases.

The debris flows and conglomerate were derived from a large dome complex or subvolcanic intrusion that was intruded into the near surface, doming the ground and creating a topographic high. Rapid erosion from the topographic high, or continued emplacement of the granodiorite, exposed the volcanic dome or subvolcanic intrusive rock, thus supplying an increasing component of granodiorite to the debris flows. The dome or intrusion then became a point source for the granodiorite detritus to the exclusion of additional volcanic material.

Erosion was rapid because the granodiorite would form a crumble (tallus) breccia that could be easily transported and rounded. Pettijohn (1957) noted that felsic crystalline rocks are mechanically less durable than fine-grained volcanic rocks and hence would become round over a short distance creating its own sandy matrix. Larger clasts also become rounded more quickly than fine-grained sands (Pettijohn 1957). This accounts for the presence of round clasts in an immature matrix.

The very coarse, poorly bedded, monolithic conglomerates were transported in a very high energy, alluvial-fluviatile, environment as discrete debris flows that left thin arenite tops to each event. The emplacement of the next debris flow would erode part of the underlying deposit leaving only remnants of bedding planes.

The very large, 2 to 3 m blocks are very difficult to transport by water in an alluvial-fluvial environment (John Wood, Northwest Regional Director, Ministry of Northern Development and Mines, Kenora, personal communication, 1987) and may have been emplaced through tectonic activity that emplaced them within the water course.

The central and southern granodiorite conglomerates may have been deposited by similar mechanisms.

Similar appearing conglomerate has been noted to the west (Davies 1983; M.G. Morrice, Geologist, Ontario Geological Survey, personal communication, 1987). These conglomerate lenses may represent a distinct period of volcanic dome building in either a wide spread subaerial environment or may themselves represent discrete volcanic islands. Growth and rapid erosion of the domes was simultaneous. The unsorted nature and cobble-sized clasts of conglomerates indicate that deposition in a proximal environment and the lack of any nearby intrusions may indicate the domes were either completely eroded or are not now exposed.

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009. Geology of the Dryberry Batholithic Complex, District of Kenora

Mary Sanborn-Barrie

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

The Dryberry granitoid terrain is an Archean batholithic complex, comprising an agglomeration of batholiths, stocks, plutons, and relict supracrustal rocks (Blackburn 1981). It is well exposed and occupies roughly 2500 km^2 in the western part of the Wabigoon Subprovince of the Superior Province. The complex is bordered by supracrustal rocks: the Lake of the Woods belt to the west (Thomson 1937; Ayer *et al.* 1987) and to the south (Johns 1987); the Warclub Group (Blackburn *et al.* 1985) to the east; and the Vermilion Bay belt (Pryslak 1976) to the north (Figure 009.1a).

The Dryberry Batholithic Complex (DBC) was investigated during the 1987 field season in order to determine:

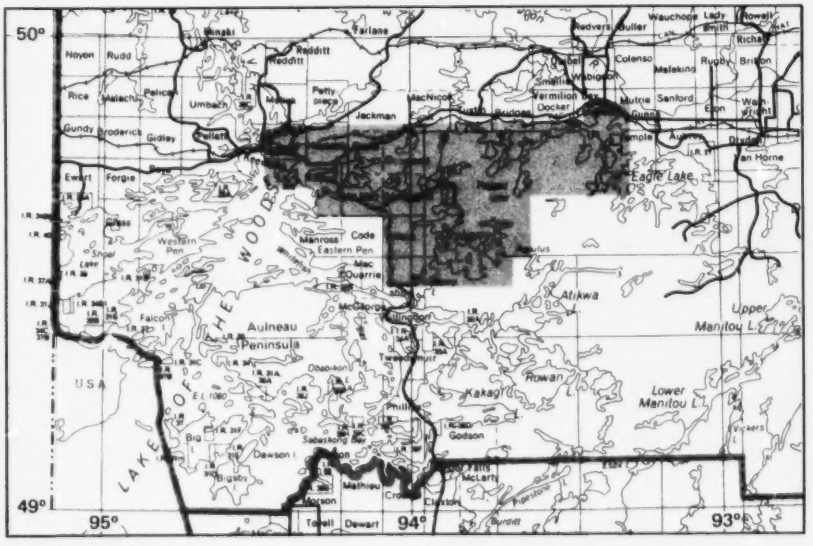
1. the petrochemical, structural, and geochronological relationships between the DBC and other intravolcanic granitoid complexes in the western Wabigoon Subprovince, and the Winnipeg River plutonic terrain to the north
2. the extent to which phases of the DBC have affected the structural style of the adjacent Lake of the Woods greenstone belt
3. the role of the DBC in the mineralization of adjacent metavolcanic sequences, particularly the eastern part of the Lake of the Woods belt
4. the role of the DBC in the evolution of the western Wabigoon Subprovince

Previous mapping of the DBC was confined to the outermost margin of the complex, where it is in contact with adjacent metavolcanics of the Bigstone Bay area (Ayer *et al.* 1987), the Gibi Lake area (Trowell 1986), the Long Bay-Lobstick Bay area (Johns 1987), and the Bruin Lake-Edison Lake area (Pryslak 1976).

In order to consider problems of regional significance as outlined above, the DBC was mapped during the 1987 field season at a scale of 1:50 000.

LITHOLOGY

Map units (Figure 009.1b) were defined on the basis of textures and mineralogy. Streckeisen's (1976) classification of igneous rocks was used to define rock names. Two principal groups of rocks are recognized: a) gneissic rocks, including paragneiss, mafic gneiss, and tonalitic orthogneiss; and b) homogeneous intrusive rocks, including quartz diorite, tonalite, granodiorite, and granite. Mineral assemblages indicate the metamorphic grade throughout the DBC is upper greenschist to lower amphibolite facies.



LOCATION MAP

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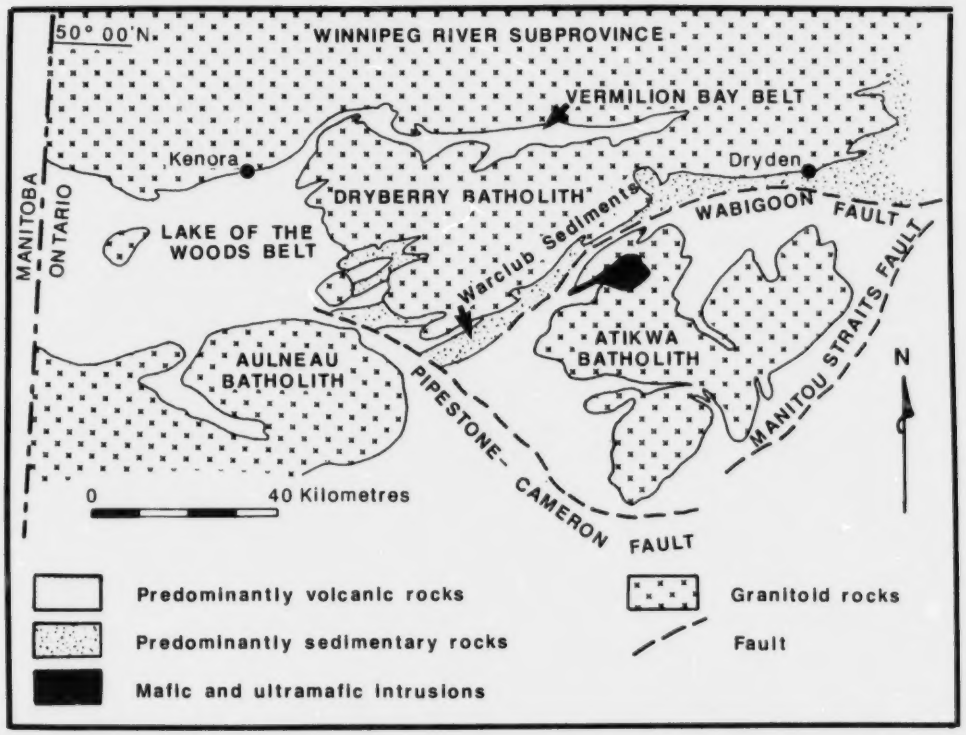

Figure 009.1a. *Location of the Dryberry Batholithic Complex in the western Wabigoon Subprovince.*

GNEISSIC ROCKS

Paragneiss

These are grey to buff weathered rocks that are layered on a millimetre- to centimetre-scale. They comprise dark grey, fine-grained biotite restite bands alternating with a light grey to rusty-buff, medium- to coarse-grained paleosome of quartz-plagioclase± biotite and minor leucosome. The degree of mineral segregation is variable, and layering may be, in part, a primary feature. These rocks are interpreted to be derived from feldspathic and quartzose wackes.

Mafic Gneiss

Two texturally distinct groups of mafic gneiss are recognized. Fine- to medium-grained amphibolite gneiss exhibits well-developed, continuous, millimetre-scale layering. Layers comprise white, plagioclase-rich bands alternating with medium- to dark-green bands of amphibole-plagioclase±biotite. These rocks are equigranular with mafic minerals comprising 30 to 50 percent of the rock. They are generally interpreted to be derived from mafic metavolcanics. Locally, field relationships suggest that mafic gneiss xenoliths may represent dismembered fine- to medium-grained mafic dikes.

Migmatized hornblende±biotite diorite is similar in mineralogy but is texturally distinct from the amphibolite gneiss. These rocks exhibit poorly segregated, discontinuous melanosome layers of dark grey-green, medium-grained amphibole±biotite diorite, with 50 to 70 percent white, medium- to coarse-grained feldspathic leucosome. These rocks may also have been derived from a mafic metavolcanic precursor. Commonly, hornblende-plagioclase±biotite metatexite is interlayered with centimetre-scale bands of fine-grained biotite-tonalite gneiss. The tonalitic interlayers may represent fine-grained dikes that were injected prior to migmatization.

Tonalitic Orthogneiss

Tonoalitic orthogneisses are homogeneous, medium-grained, biotite-plagioclase-quartz±K-feldspar-magnetite rocks. Minor K-feldspar may be primary but typically appears to be a metasomatic addition, occurring as diffuse patches and veins. Rarely, hornblende is present in addition to biotite. These rocks exhibit a variety of textures. In their least deformed state they are moderately to strongly foliated. More typically they exhibit a weakly gneissic texture or "streaky gneiss" (Photo 009.1) characterized by discontinuous wisps of biotite restite in a strongly foliated quartzofeldspathic matrix. Progressive migmitization leads to the development of a "lumpy gneiss" (Photo 009.2) in which lumpy aggregates of white, medium-grained quartzofeldspathic material are enveloped by folia of biotite restite.

Tonalitic orthogneiss is volumetrically the most significant of the gneissic rocks. At most localities where paragneiss or mafic gneiss is observed, these units are both injected by, and are contained as

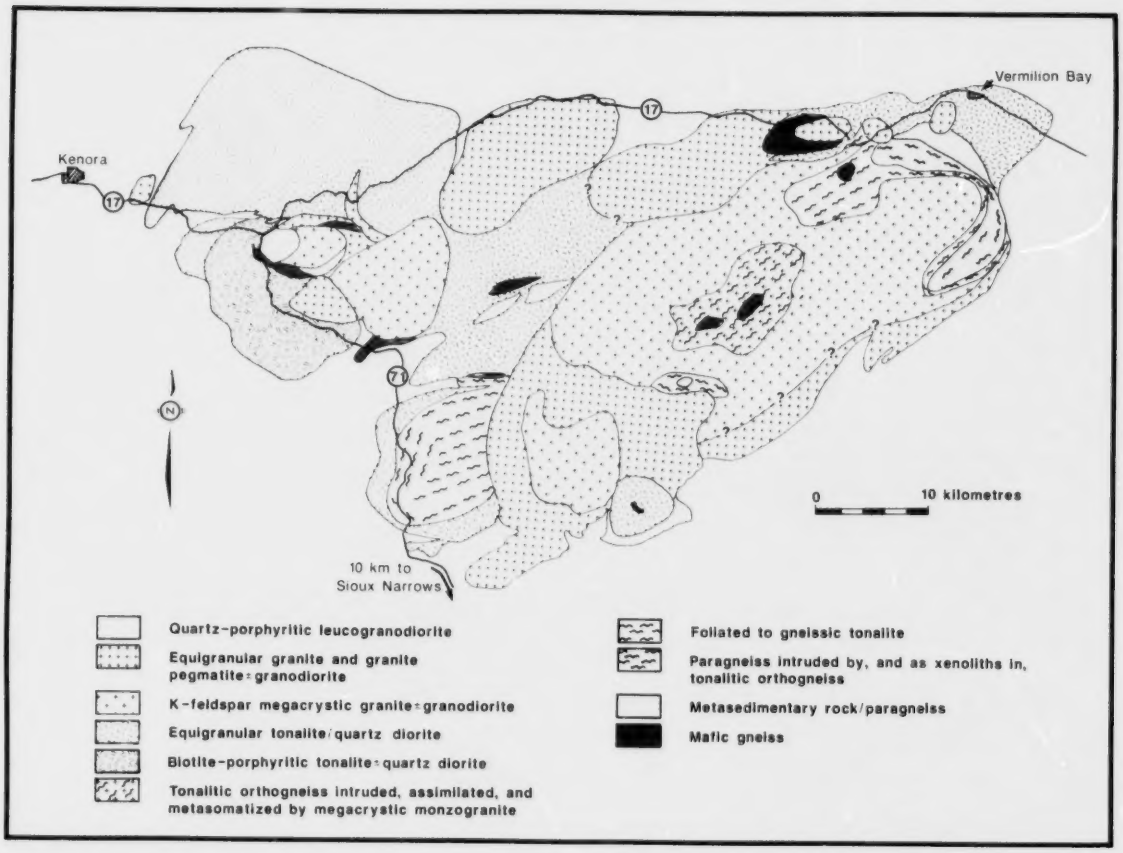

Figure 009.1b. *Geological map of the Dryberry Batholithic Complex.*

xenoliths and large rafts within, biotite tonalite orthogneiss.

HOMOGENEOUS INTRUSIVE ROCKS

Biotite-Porphyritic Tonalite

Homogeneous, foliated biotite tonalite occurs as a mappable phase in the western part of the DBC. Biotite occurs as subhedral books, 4 to 8 mm, which generally form 8 percent of the rock. Biotite occurs also as clots, 5 to 15 mm, comprised of elliptical aggregates of fine-grained flaky biotite with associated fine disseminated epidote and magnetite. Biotite is contained within a medium-grained, equigranular groundmass of quartz (20 to 25 percent) - plagioclase (50 to 60 percent) ±biotite-epidote-magnetite. Magnetite (1 to 3 percent) occurs as disseminated 1 mm crystals. Locally these rocks may be quartz- and/or plagioclase-porphyritic. Rarely, they are quartz dioritic, containing 10 to 15 percent quartz.

Equigranular Tonalite/Quartz Diorite

Equigranular, medium-grained biotite tonalite±quartz diorite is a widespread phase in the western half of the DBC. These rocks comprise individual plutons and also occur as a marginal phase to biotite-porphyritic tonalite. They are homogeneous equigranular medium-grained rocks composed of plagioclase-quartz-biotite±amphibole±magnetite. The quartz content is typically 15 to 25 percent. These rocks may contain up to 7 percent hornblende in addition to biotite, within the western margin of the DBC where they are in contact with mafic metavolcanics of the Lake of the Woods greenstone belt.

K-feldspar Megacrystic Monzogranite/Granodiorite

These rocks occupy most of the eastern region of the DBC and also form a discrete pluton in the western region. In the east, megacrystic monzogranite contains K-feldspar both as megacrysts and as 1 to 2 mm grains in a medium-grained groundmass of quartz-plagioclase-K-feldspar-biotite-magnetite± epidote. These rocks contain up to 4 percent magnetite, which may be very finely disseminated (<0.5 mm) or may occur as irregularly scattered 1 to 3 mm blebs. Megacrysts of K-feldspar generally compose 5 to 12 percent of the rock and rarely may compose up to 40 percent of the rock. These megacrysts average 10 mm in length and vary between 5 mm and 20 mm in length. Two forms of megacrysts are observed: equant crystals with diffuse outlines, or sharply outlined lath-shaped crystals. Lath-shaped megacrysts typically exhibit moderate to well developed flow alignment. Both forms of K-feldspar mega-

crysts contain 1 to 2 mm inclusions of quartz, plagioclase, K-feldspar, and/or biotite, suggesting a late-stage growth of the megacrysts. Some megacrysts also exhibit internal zoning, usually enhanced by the arrangement of included grains.

An ovoid K-feldspar megacrystic pluton in the western part of the DBC is granodioritic in composition, with K-feldspar constituting 20 to 25 percent of the total feldspar. Megacrysts compose 5 to 10 percent of the rock and always occur as diffuse, poikilitic crystals with square sectional outlines. Lath-shaped megacrysts were not observed. This unit has a medium-grained groundmass of plagioclase-quartz–K-feldspar-biotite±epidote±magnetite. Quartz occurs both as interstitial grains and as 4 to 8 mm hematized quartz eyes. Biotite occurs as 1 to 2 mm flakes (up to 10 percent) and in subrounded, 2 to 4 mm patches (3 percent). Very fine grains of epidote are spatially associated with biotite.

Equigranular Monzogranite/Granodiorite

These rocks generally occur as marginal phases to the K-feldspar megacrystic plutons. They are medium-grained, equigranular, light pink-weathering rocks comprised of plagioclase-quartz–K-feldspar-biotite±epidote±magnetite.

In the eastern and southeastern margins of the DBC, equigranular monzogranite rocks are two mica (muscovite and biotite) and garnet bearing. Muscovite occurs as 2 mm booklets (5 percent) and rose-coloured garnets occur as fine disseminated grains, (generally less than 1 percent). It may be possible to classify these rocks as peraluminous, following thin section and petrochemical work. A peraluminous granitoid suite is recognized in the Dryden-Vermilion Bay area to the east, by Breaks *et al.* (1985).

Quartz-Porphyritic Leucogranodiorite

This is a distinctive rock type which forms a small circular plug in the west-central part of the DBC and

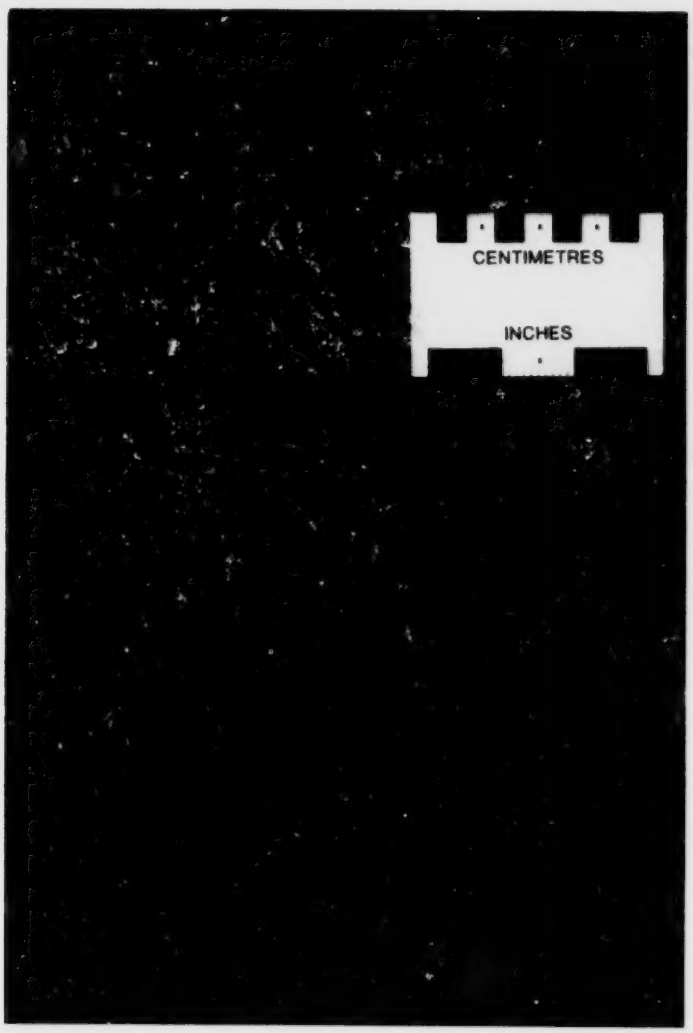

Photo 009.1.
Homogeneous tonalitic orthogneiss with discontinuous wisps of biotite restite in a strongly foliated quartzo-feldspathic matrix. This texture is referred to as "streaky gneiss".

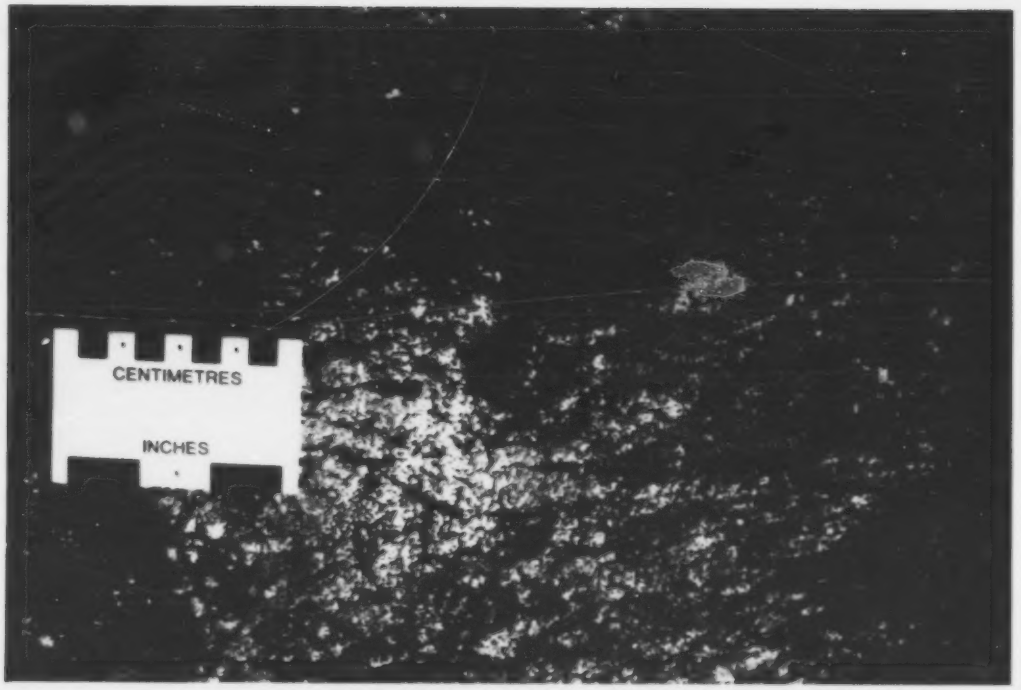

Photo 009.2. *Tonalitic orthogneiss with aggregates of quartzofeldspathic minerals enveloped by biotite folia. This texture is referred to as "lumpy gneiss" and is interpreted to represent incipient anatexis.*

also occurs as minor marginal phases in the western and southern regions. It is bright pink weathered and comprises up to 8 percent quartz phenocrysts, 8 to 10 mm in length, in a fine-grained groundmass of plagioclase-quartz–K-feldspar-epidote±magnetite± biotite. Quartz eyes are both clear and wine red, the latter due to hematite staining. Fine-grained epidote is both disseminated throughout the rock and concentrated in elliptical clots up to 10 mm in length. Very fine magnetite is commonly a constituent of the epidote-rich clots, and rare ragged biotite is observed. Epidote, magnetite, and biotite together constitute less than 8 percent of this unit.

Pegmatite

Pegmatitic and aplitic phases are commonly associated with the K-feldspar megacrystic monzogranite. These are quartz–K-feldspar±plagioclase-biotite-magnetite rocks, most commonly of syenogranite to monzogranite composition. Pegmatitic phases may constitute entire outcrops, or may occur as patches or dikes within the equigranular and megacrystic monzogranite. Pegmatite dikes are commonly zoned, with quartz cores enveloped by parallel segregations of feldspar and/or mica.

In the eastern margin of the DBC, granite pegmatite contains garnet (2 to 4 percent) and muscovite (5 to 8 percent) in addition to biotite. These accessory minerals suggest a peraluminous association.

STRUCTURE

GNEISSIC LAYERING

The earliest structure recognized is gneissic layering (S_1) in paragneiss and mafic gneiss. Attitudes of gneissosity are variable; however, northwesterly to northeasterly trends predominate across the map area (Figure 009.2). Dips are generally steep (65° to 85°), both to the west and to the east. Moderate to shallow dips are confined to several marginal areas of the complex (Figure 009.2). North- and northwest-trending gneissic layers typically exhibit open to gentle buckle folds (90° to 180° interlimb angle) with easterly trending axial planes. Moderate west- and northwest-plunging fold axes are most commonly observed. In contrast, gneissic layers that trend northeasterly and easterly are typically unfolded. Only at one locality in the extreme northeastern part of the DBC is open buckling of north-northeasterly trending gneissosity observed.

In the south-central part of the DBC (south of locality B; Figure 009.2), trajectories of gneissosity partly define a circular gneissic pluton. More commonly, trends in S_1 gneissosity are discontinuous (Figure 009.2), since S_1 is typically recorded from large gneissic rafts and xenoliths.

FOLIATION

Most homogeneous plutonic rocks within the DBC exhibit some degree of mineral alignment. This foliation is referred to here as S_2, since these rocks commonly contain xenoliths of material that exhibit

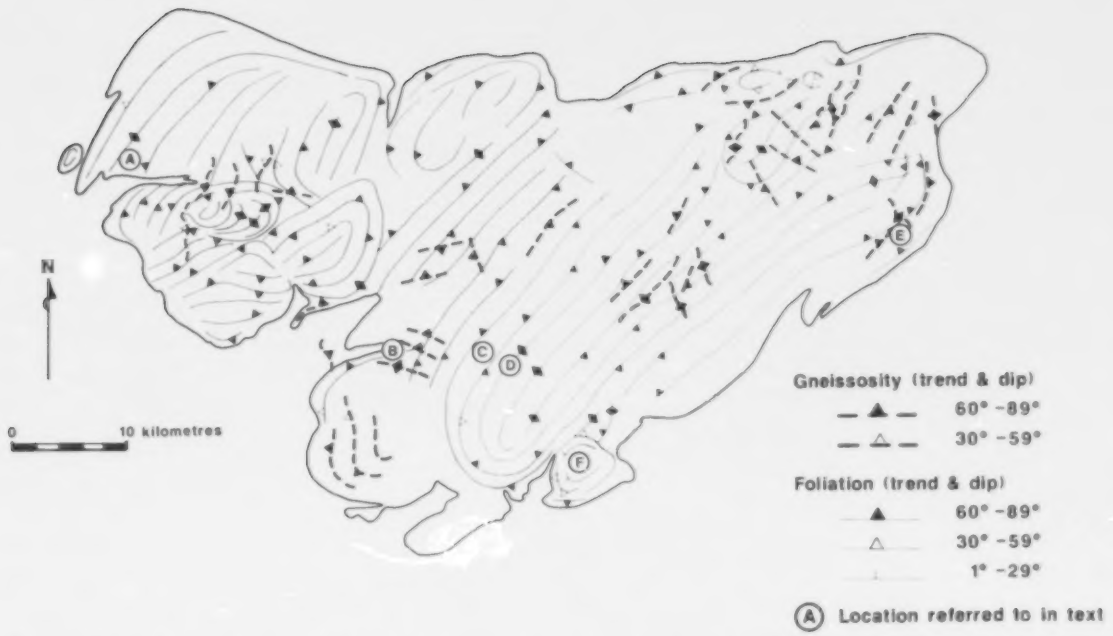

Figure 009.2. *Summary map of the planar structural elements in the Dryberry Batholithic Complex.*

S_1. Foliation trends differ greatly between the eastern and western parts of the DBC. The eastern two thirds of the complex is dominated by homogeneous, foliated megacrystic monzogranite that exhibits a remarkably consistent northeasterly trending foliation. This fabric is defined consistently by aligned biotite flakes and elongate quartz grains. K-feldspar megacrysts may also be aligned parallel to S_2. However, where megacrystic monzogranite is injected into a previously foliated to gneissic rock, megacrysts most typically exhibit flow alignment parallel to S_1, with interstitial biotite and quartz aligned parallel to S_2. As such, flow aligned megacrysts are commonly interpreted as a **primary emplacement** fabric (S_{2a}), controlled by and thus parallel to S_1. In contrast, aligned biotite and elongate quartz that are interstitial to the megacrysts (S_{2b}) may be interpreted as: a) a **primary expansion** (or ballooning) fabric, b) a regional tectonic fabric, or c) a combination of these.

Throughout the eastern region, the intensity of development of S_2 is generally moderate to moderately strong. Rarely, S_2 is weakly developed. Field estimations of L (constriction) versus S (flattening) fabric elements, indicate that the degree of constriction does not exceed that of flattening, and hence L<S is uniform across the eastern part of the DBC.

In the south-southeast part of the DBC (locality F; Figure 009.2), topographic features outline a concentric structure, 3 km in diameter. This structure comprises homogeneous, subhorizontally foliated tonalite, interlayered with shallowly-dipping sheets of mafic gneiss and possible paragneiss. Foliation trends and lithological contacts define an outward-dipping domal structure with moderately-dipping (45°) margins and a subhorizontal core.

The western part of the DBC is characterized by concentric foliation patterns that parallel the lithological contacts of individual plutons. Foliation dips are steep to subvertical. The intensity of foliation development within individual plutons is variable, being absent to weak in the core, and moderate to strong at the pluton margins. L/S fabrics may also vary across individual plutons, and commonly indicate constriction (L>S) in the core of individual plutons, and increasing flattening (L<S) toward the pluton margins.

MINERAL LINEATIONS

Mineral and stretch lineations parallel the direction of maximum extension in a rock and, for the purposes of this study, can provide valuable information concerning: a) the mode of emplacement of magmas, b) changing stress regimes, and c) tectonic overprinting. Throughout the DBC, attitudes of mineral lineations exhibit two dominant patterns. The eastern part of the complex is characterized by mineral lineations that plunge moderately to steeply (55° to 80°) in a northeasterly and easterly direction. The western part of the complex, in contrast, is characterized by mineral lineations that plunge radially outward from the centres of individual plutons. As a rule, mineral lineations of individual plutons plunge steeply where L>S, and plunge moderately where L<S.

FAULTS, SHEAR ZONES, LINEAMENTS, AND ASSOCIATED ALTERATION

Fault-related structures were rarely observed in the DBC. Particular attention was focused on those areas that coincide with aerial photograph lineaments, as displayed on the regional compilation map (Blackburn

1981). Apart from the two localities described below, aerial photograph lineaments were not found to coincide with tectonic structures. At locality C (Figure 009.2), a 60 cm wide zone of mylonitized rock is exposed for a strike length of 5 m. These rocks are contained within a brittle-ductile shear zone that strikes eastward (092°) and dips steeply south. Shallow, east-plunging mineral lineations indicate a major component of transcurrent (strike slip) displacement. Composite C/S fabrics (Simpson and Schmid 1983) and the curvature of external schistosity into the shear zone are indicative of dextral displacement. This shear zone was the only notable tectonic structure recognized as coincident with an easterly trending lineament which extends some 30 km across the southern part of the DBC (Blackburn 1981). No other structural evidence was observed to indicate that this lineament represents a major tectonic break.

Locality D is located in the intersection region of two low-angle, easterly trending lineaments and coincides with an area where rock compositions and textures suggest the contemporaneous emplacement of mafic and felsic magmas. For instance, over a strike length of at least 1 km, two end-member compositions, monzogranite and hornblende-porphyritic (lamprophyric?) gabbro, are found in close spatial association. Textures such as skeletal hornblende in monzogranite, net-vein textures of monzogranite in gabbro, and amoeboidal masses of gabbroic material in monzogranite suggest possible mixing of felsic and mafic magmas (Davis and Edwards 1985; Sutcliffe and Sweeney 1985). Both gabbroic and granitic rocks exhibit a weak to moderate foliation which is parallel to the dominant northeasterly trending foliation (S_{2b}) in the eastern part of the DBC. A spatial association between regional lineaments and areas of mixed mafic and felsic magmas is recognized in the Atikwa-Lawrence batholithic complex (D. Davis, Geochronologist, Royal Ontario Museum, Toronto, personal communication, 1987), located southeast of the DBC (Figure 009.1a). This association might suggest that some regional lineaments may represent deep-seated structures, along which magma has been emplaced.

Areas transected by numerous centimetre- to metre-scale shear zones occur at localities A, B, and E (Figure 009.2). At locality A, a system of conjugate shear zones was observed: one set trends southward, dips moderately (65°) west and exhibits dextral transcurrent differential displacement; a second set trends north-northwest, dips moderately (65°) east and exhibits reverse, (east-side-up) displacement. Locality B is transected by a 3 m wide, northeast-trending shear zone which is characterized by extreme grain size reduction of quartz and feldspar and by hematitic alteration. Mineral lineations indicate that the maximum extension is steep and to the northwest (down dip). A preliminary interpretation of displacement in a reverse (northwest-side-up) sense will require confirmation by microfabric analysis. Locality E is within the eastern margin of the DBC. Here, numerous easterly trending shear zones, 2 to 20 mm wide, transect equigranular monzogranite. Apparent minor dextral movement is documented by the offset of pegmatite dikes and by the deflection of S_2 foliation.

Although the significance of the structures at these localities remains to be evaluated, there is little evidence (with the exception of location B) that they have acted as channelways for migrating hydrothermal fluids. There is a notable absence of quartz stockwork systems and secondary minerals such as iron-carbonate, sericite, hematite, and chlorite. Discrete epidote-filled fractures with enveloping hematized zones are observed throughout the K-feldspar megacrystic monzogranite to granodiorite suite which dominates the eastern part of the DBC.

CHRONOLOGY

By virtue of crosscutting relationships and the intensity of foliation development, the relative timing of emplacement of the major phases of the DBC can be constructed. Supracrustal rocks appear to be the oldest. This includes metasedimentary units and mafic rocks of probable metavolcanic origin. Interlayered biotite tonalite gneiss probably represents early dikes or sills that were intruded into the supracrustal sequence. Strongly foliated biotite tonalite and homogeneous tonalitic orthogneiss host most of the metasedimentary and mafic supracrustal xenoliths. Tonalitic orthogneiss occurs as xenoliths and as highly assimilated and metasomatized relict xenoliths in younger foliated equigranular and megacrystic monzogranite. Massive to foliated domical plutons are late in the magmatic history of the complex. Relative age relationships between adjacent late plutons, particularly in the western part of the DBC, will be assessed with a more detailed examination of the fabric relationships.

ECONOMIC GEOLOGY

Several occurrences of gold mineralization are known to exist within the northwestern margin of the DBC (Beard and Garratt 1976; Davies *et al.* 1985; Ayer *et al.* 1987; Blackburn *et al.* 1987; Figure 009.3). Lithological and structural relationships at two of these occurrences, the Sweden and the Silverman, were investigated as part of this study.

The Sweden Occurrence is hosted by quartz diorite which locally contains numerous mafic metavolcanic xenoliths. Typically, large rafts of mafic metavolcanics exhibit net-vein textures of quartz diorite, while smaller mafic xenoliths show evidence of metasomatism and assimilation by the intruded dioritic material. Fine-grained felsite dikes (2 to 20 cm wide) cut the xenolithic quartz diorite and appear to form a conjugate 030°- and 090°-trending set. The property is transected by a 2.5 m wide, northeast-trending, southeast-dipping shear zone which is localized within a mafic-rich part of the xenolithic quartz diorite. The shear zone is characterized by shallow (28°) southwesterly-plunging mineral lineations and shear bands corresponding to composite C/C′ fabrics (Platt 1984). Together these indicate a major dextral transcurrent displacement with a minor component of normal (east-side-down) displacement. A 20 cm wide felsite dike, contained within the shear zone, exhibits sigmoidal, asymmetric, Z folds (consistent with dextral shear), which would indicate that shearing postdated all magmatic activity. A shaft was sunk to a depth of 21 m on the shear zone, and

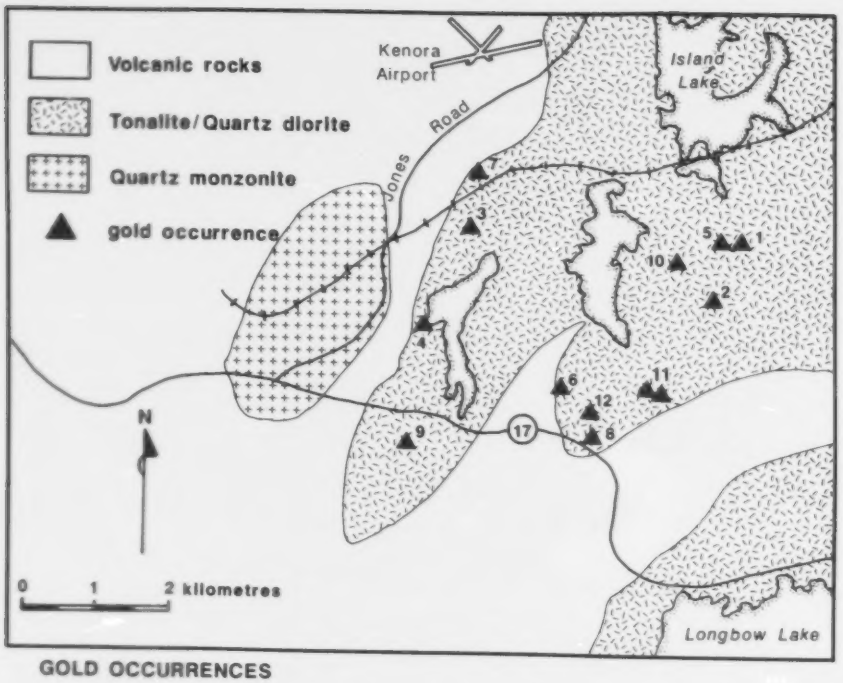

Figure 009.3. *Location of known gold occurrences in the Dryberry Batholithic Complex after Blackburn et al. (1987).*

GOLD OCCURRENCES

1 Champion	5 Norway	9 Split Lake Occurrence
2 Emmons	6 Roseman	10 Sweden
3 Eschweiler	7 Royal	11 Treasure
4 Hilly Lake	8 Silverman	12 Westin

although carbonate, silica, and thin discontinuous felsite dikes occur in the shear zone, it is not apparent where gold was specifically localized. Sulphide mineralization occurs as fine disseminated pyrite in sheared felsite, and as blebs of pyrite with minor chalcopyrite in sheared quartz diorite.

The Silverman Occurrence is located 10 km south of the Sweden Occurrence and is underlain by homogeneous tonalite and minor quartz diorite. Both lithologies exhibit a weak to moderately-developed penetrative foliation which trends north-northeasterly, and both are transected by numerous, parallel, millimetre- to metre-scale shear zones. Shear zones trend 050° to 060°, dip westward (70° to 80°), and contain mineral lineations that plunge moderately (60° to 65°) northeastward. Shear bands corresponding to composite C/C′ fabrics, and the curvature of external foliation into the shear zone indicate a major normal (northwest-side-down) movement and minor dextral displacement. The development of a penetrative (020°) foliation and northeasterly trending high strain zones is consistent with south-southeasterly directed, subhorizontal, compressive stress. Gold mineralization is localized within centimetre- to metre-scale quartz-tourmaline veins in tonalite. Although wall rock adjacent to the quartz-tourmaline veins may exhibit high strain, field relationships suggest that the veins were formed prior to the shearing event. For instance, quartz-tourmaline veins at a high angle to the plane of flattening (020°) commonly exhibit tight symmetric folds, typical of buckle folds produced during bulk shortening. Quartz-tourmaline veins at a low angle to the flattening plane exhibit asymmetric Z folds, compatible with rotation of the veins toward the plane of shear. Localized high strain adjacent to the veins may, in part, reflect a contrast in competency between the veins and the host rock. Visible gold is reported (Thomson 1947) to have been distributed erratically in the quartz-tourmaline veins, with minor pyrite, pyrrhotite, and traces of chalcopyrite.

SUMMARY

The DBC comprises minor paragneiss and mafic gneiss, tonalitic orthogneiss, and a number of homogeneous, massive to foliated plutonic phases. Field relationships indicate that emplacement of its various components took place in episodes over an extended period of time. A preliminary magmatic chronology is presented here, and it is hoped that absolute timing of the major phases of the complex will be constrained by U-Pb zircon geochronology. A number of known gold occurrences are contained within a marginal tonalitic/quartz dioritic phase of the DBC. In addition, a number of known gold occurrences and a past-producing gold mine (Ayer *et al.* 1987) are contained within an aureole of contact strain, imposed on the Lake of the Woods greenstone belt by the western marginal phases of the DBC. These relationships clearly indicate the potential for gold mineralization within, and proximal to the DBC.

The DBC is one of a number of Archean granitoid complexes that together comprise over 80 percent of the surface outcrop in the Superior Province. The study of these rocks is essential to understanding the structural relationships between the granitoid rocks and the greenstone belts, the relationship between plutonism and gold mineralization, and crustal evolution in the Archean.

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010. Geology of the High Lake Area, Ewart Township, District of Kenora

P. Mark Smith

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

Field investigations in 1987 were concentrated around the eastern end of High Lake, roughly 45 km west of the Town of Kenora (Location Map). An area of 12.5 km^2 was mapped at a scale of 1:3937. The purposes of this work were to reexamine a previously documented metal zonation and alteration pattern surrounding the western phase of the High Lake Stock (Pedora 1976), to examine the structural and metamorphic patterns in the area and their relationships to mineralization, and to study the sedimentary rocks of the Crowduck Lake Group, which unconformably overlie the eastern phase of the High Lake Stock.

GENERAL GEOLOGY

Mapping at a scale of one inch to one half mile (1:31 680) of the High Lake area by Davies (1965) provided a fundamental understanding of the regional geology and formed the basis for both this study and earlier metallogenic investigations (Pedora 1976; Colvine and Sutherland 1979).

A northeast-facing succession of mafic to felsic metavolcanics has been intruded by two phases of the High Lake Stock and related porphyritic granodiorite dikes. The metavolcanics and the eastern phase of the High Lake Stock are unconformably overlain by metasediments of the Crowduck Lake Group. Two major periods of deformation affect the rocks near High Lake (Davies 1965). The first deformation event (D_1) is manifested as large open to close folds (F_1), and the second deformation event (D_2) is characterized by tight shear folds (F_2) consistent with a dextral sense of displacement (Davies *et al.* 1985).

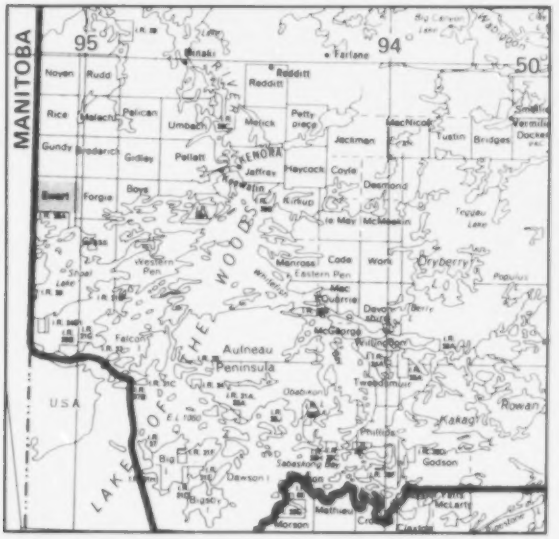
DETAILED GEOLOGY

VOLCANIC ROCKS

The oldest rocks in the study area, originally defined as "Keewatin" (Davies 1965), occur immediately east of the High Lake Stock, and consist of medium-grained massive, and fine-grained pillowed basalts overlain by felsic pyroclastic rocks (Figure 010.1). The felsic extrusive rocks are texturally similar to, and difficult to distinguish from, the eastern phase of the High Lake Stock. These felsic extrusive rocks may represent an outlier of the felsic volcanic sequence (preliminary U-Pb zircon age of 2.723 Ga, D. Davis, Geochronologist, University of Toronto, personal communication, 1986) exposed mainly to the north and east of the Crowduck Lake Group.

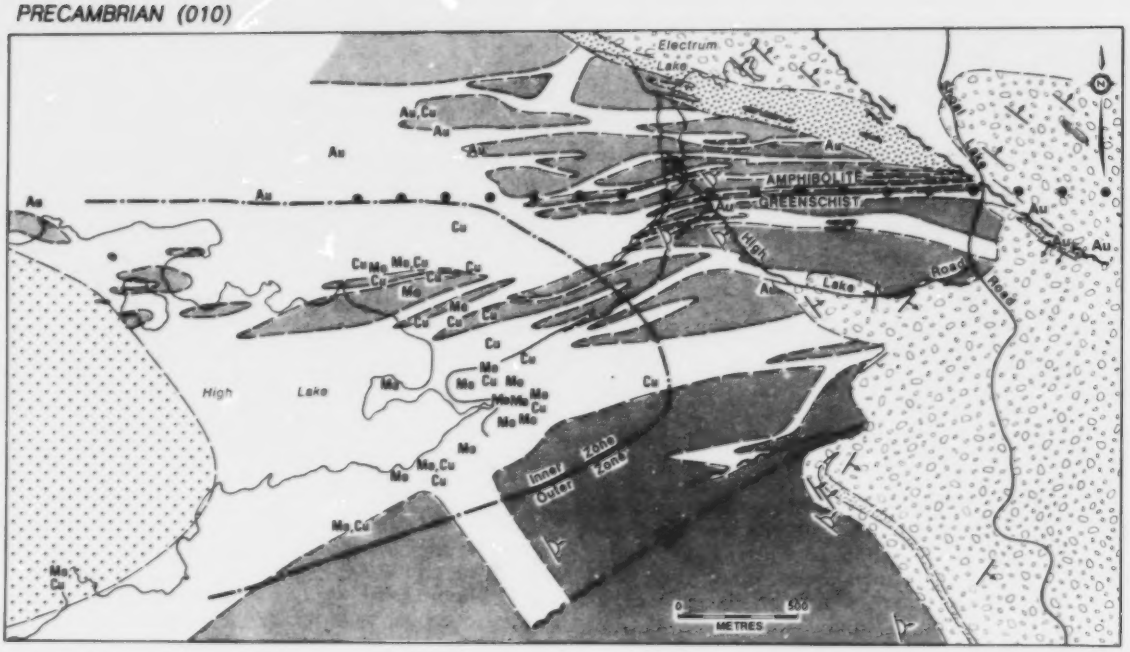
THE HIGH LAKE STOCK

The High Lake Stock has been discussed by earlier workers (Davies 1965; Pedora 1976; Colvine and Sutherland 1979) and the reader is referred to those



LOCATION MAP

Scale : 1:1 584 000 or
1 inch to 25 miles



WESTERN PHASE OF HIGH LAKE STOCK
Granodiorite, tonalite

CROWDUCK LAKE GROUP
Conglomerate, quartz arenite, pebbly quartz arenite, greywacke, arenite, siltstone, argillite, chemical sediments and felsic to mafic tuffs.
Clinopyroxene-phyric basalt

EASTERN PHASE OF HIGH LAKE STOCK
Porphyritic granodiorite, trondhjemite and granodiorite

VOLCANIC ROCKS
Felsic pyroclastic rocks, in part intrusive
Basalt
Cu,Mo,Au Copper, Molybdenum and Gold occurrences
Tops determined from graded bedding, flame structures, cross bedding and/or scours
Tops determined from pillow facings
Boundary between metal zones
Metamorphic isograd
Fault, or shear with dextral movement

Figure 010.1. *Geology of the High Lake area.*

discussions to supplement the observations summarized below.

Eastern Phase

The eastern phase of the High Lake Stock is porphyritic granodiorite to trondhjemite (Pedora 1976). Although generally porphyritic, in places the eastern phase is massive and equigranular, and difficult to distinguish from the western phase. In general, the eastern phase ranges from grey to salmon pink in colour, is fine to medium grained, and contains megacrysts of quartz, plagioclase, and potassium feldspar. Euhedral feldspar megacrysts are up to several centimetres in length, while the more abundant, anhedral to subhedral, quartz phenocrysts are generally less than 5 mm long.

A porphyritic granodiorite dike swarm, which occurs east of the High Lake Stock, is interpreted to be part of the eastern phase. The dikes are similar in colour and texture to the porphyritic granodiorite of the eastern phase and can be traced into the main body of porphyritic granodiorite (Figure 010.1). Within individual dikes, quartz megacrysts are ubiquitous; however, the concentration of feldspar megacrysts is variable within any single dike, and is more obviously variable between different dikes, ranging from 0 to 15%.

Western Phase

The western phase of the High Lake Stock is tonalite to granodiorite (Pedora 1976). This phase, which is homogeneous throughout the area examined, is generally massive, medium grained, and equigranular, but locally contains rare feldspar megacrysts similar to those observed in the eastern phase. It contains abundant, partially assimilated, mafic xenoliths and displays a well-developed flow layering parallel to the intrusion's margins. In general, biotite and hornblende are more abundant than in the eastern phase. They are commonly found in small clots, possibly reflecting the assimilation of mafic xenoliths. Aplite dikes occur locally within this phase.

Intrusive Contacts and Timing of the Two Phases

The age relationships between the two intrusive phases could not be determined definitively. The current field program failed to locate an exposed contact, although examination of available exposure did result in a shift of the contact some 1.5 km to the

west of an earlier map location (Davies 1965). As well, no dikes or xenoliths of either phase were found in the other. The geometry of the contact, wherein the western phase is convex into the eastern phase, suggests that the former intrudes the latter. Furthermore, a penetrative cataclastic fabric is generally present within the eastern phase but is absent from the western phase (Vagt 1968 *in* Pedora 1976; Pedora 1976), suggesting that the western phase is younger. In some locations, a penetrative foliation and cataclastic fabric are present in both the "Keewatin" basalts and the porphyritic granodiorite of the eastern phase of the stock, several metres from the contact with the western phase. Neither fabric is present in rocks of the western phase. The penetrative foliation in the eastern phase near the contact is characterized by flattened quartz phenocrysts and may reflect a contact strain aureole of the western phase.

Preliminary U-Pb zircon ages of the two phases also suggest that the western phase is younger (D. Davies, Geochronologist, University of Toronto, personal communication, 1986). The eastern phase of the stock is 2.724 Ga, indicating that it is synvolcanic (see above), while the western phase is younger than 2.714 Ga.

THE CROWDUCK LAKE GROUP

The Crowduck Lake Group (Figure 010.1) is composed of sedimentary rocks which are locally intercalated with highly vesicular clinopyroxene-phyric basalts and mafic to felsic pyroclastic rocks. The sedimentary rocks of the Crowduck Lake Group consist mainly of poorly sorted conglomerates, arenites, quartz arenites, and greywackes, intercalated with siltstones, mudstones, argillites, and chemical sediments, including banded iron formations.

Poorly sorted conglomerate is the most common sedimentary rock in the study area. Texturally it ranges from matrix to clast supported, and contains a diverse range of clast types and sizes. Clasts are subrounded to angular, and are up to several metres in diameter. Clast lithologies include porphyritic granodiorite of the High Lake Stock, quartz diorite, mafic (in places variolitic), intermediate and felsic volcanic rocks, banded iron formation, chert, mudstone, arenite, greywacke, and conglomerate. In some units one clast type predominates, suggesting a local origin. Other units contain diverse clast types and sizes, including sedimentary clasts, suggesting reworking of earlier sediments, or a varied source terrain. Large scour channels are common within these sequences, suggesting a debris flow environment.

In the northeast portion of the study area (Figure 010.1) is a sequence of pebbly quartz arenites. This sequence is composed of numerous distinct units, each only several metres thick, which fine upwards from a pebbly base through sand to a silty, laminated top. These units may also be debris flows.

In the southeastern portion of the study area, conglomerates, cherts, wackes, and mudstones of the Crowduck Lake Group are overlain by clinopyroxene-phyric basalts and pyroclastic block and ash flows. These in turn are overlain by more conglomerates and arenites, which are locally interbedded with intermediate tuffs.

The ages of the sedimentary and volcanic rocks in the Crowduck Lake Group remain uncertain. The group was originally designated as "Timiskaming" by Davies (1965), because of its angular, unconformable relation with basalt and porphyritic granodiorite dikes along the western boundary of the group, and because of the presence of porphyritic granodiorite clasts in sedimentary rocks of the group. Davies (1965) also suggested that sediments in the northern and eastern portions of the Crowduck Lake Group are "Keewatin"; however, in some locations these sediments are intercalated with, scour, and contain fragments of rocks which Davies (1965) has designated as "Timiskaming". Thus they are either part of, or younger than, the Crowduck Lake Group.

THE UNCONFORMITY

The angular unconformity between the Crowduck Lake Group and the underlying volcanic terrain displays a highly irregular paleosurface. Contact relationships are complicated by F_2 folds and associated dextral shearing (*see* below). In the study area, the structural facing direction is northeast to east within the Crowduck Lake Group, but close to the unconformity it is locally southerly or northerly where the unconformity strikes east (Figure 010.1).

Small embayments of conglomerate into the underlying basalts and granodiorite dikes (Figure 010.1) are filled by finely laminated siltstones, mudstones, and cherts locally intercalated with wackes and pebbly quartz arenites. In places these sediments have been scoured by conglomeratic and pebbly quartz arenite debris flows. The volcanic and granodiorite dikes further to the east are directly overlain by conglomeratic debris flows and pebbly arenites. In the northeastern portion of the study area, where the arenite and granodiorite dikes are in contact (Figure 010.1), the contacts are themselves at a high angle to bedding and may reflect the shape of paleobasin walls.

METAMORPHISM

All of the volcanic rocks in the study area have been metamorphosed to at least lower greenschist facies.

There is a distinct, amphibolite facies, contact metamorphic aureole surrounding the High Lake Stock. Narrow amphibolite aureoles also surround wider porphyritic granodiorite dikes some distance from the intrusion.

An amphibolite-facies metamorphic aureole extends south from the English River Subprovince into the study area (Figure 010.1). Since the field identification of this aureole is based on the presence of garnet and hornblende porphyroblasts, and the development of such minerals is dependent on the protolith, the precise placement of the isograd can only be delimited by petrographic study, which will be undertaken during the upcoming winter.

STRUCTURAL GEOLOGY

D_1 is characterized by large-scale, shallowly plunging regional folds (F_1) whose axes were originally northwest trending (Davies 1965). No fabric was recognized which could be directly assigned to the D_1 event in the study area, as is true elsewhere in the northern part of the Lake of the Woods greenstone belt (Smith and Thomas 1986).

D_2 is characterized by a strong, easterly trending, penetrative foliation, and/or a cataclastic fabric, and/or a space cleavage. These are superimposed on all of the rocks in the High Lake area, except in the western phase of the High Lake Stock. The development of these fabrics is dependent on the competency of the protolith. They are axial planar to F_2 shear (similar) folds. Lineations in the area pitch 40° to 60° west, presumably orthogonal to the hinge line of the F_2 folds. Within the study area, shear zones deflect around the main body of the High Lake Stock. Farther to the east, the shears are mainly east trending. Here they parallel F_2 fold axes and strain is greatest along fold limbs. Without exception, these shears are strike slip, and kinematic indicators suggest that they are dextral, with north-side-up movement.

Sedimentary rocks are most affected by the D_2 event. Foliation is locally intense, and in places preexisting, synsedimentary structures such as scour channels have been exaggerated by the D_2 event. This is particularly evident where a more competent lithology has been scoured by a less competent sediment. In such a case the sediment takes up most of the strain, and acts in a ductile fashion, being squeezed between two competent blocks.

MINERALIZATION

Sulphide and gold mineralization is distributed around the western phase of the High Lake Stock in a zonal pattern (Davies 1965; Pedora 1976). The inner zone, closest to the western phase of the stock (Figure 010.1), is characterized by molybdenite, chalcopyrite, magnetite, and pyrite mineralization. Occurrences within the outer zone (Figure 010.1) are enriched in gold and pyrite, locally containing arsenopyrite, chalcopyrite, sphalerite, and/or galena.

Molybdenite is found within, or immediately surrounding, quartz veins hosted in porphyritic granodiorite. In a massive host rock, these quartz veins are tension veins; within discrete shear zones, they are shear veins. Chalcopyrite, either disseminated or occurring in stringers, is found in several locations within the porphyritic granodiorite. Chalcopyrite also locally occurs in basalt inclusions within the porphyritic granodiorite. Invariably, the copper mineralization is associated with magnetite (Davies 1965). Molybdenite and chalcopyrite have also been observed on slip surfaces at one location within the granodiorite of the western phase of the High Lake Stock (C.E. Blackburn, Resident Geologist, Ontario Ministry of Northern Development and Mines, Kenora, personal communication, 1987).

Gold mineralization in the High Lake area occurs in quartz veins and/or silicified shears which formed during the D_2 event. These structures and associated gold mineralization occur in all rocks in the High Lake area except in the western phase of the High Lake Stock. Many of the occurrences are located along the margins of porphyritic granodiorite dikes where there is a strong competency contrast with the host rock. Magnetic anomalies are associated with many of these occurrences.

ALTERATION

Alteration associated with Mo-Cu mineralization is widespread. The porphyritic granodiorite of the High Lake Stock west of most of the Mo-Cu occurrences is characterized by fine quartz stringers and silicification. Closer to the mineralization, the granodiorite is salmon pink. This colour is associated with a stockwork of quartz veins and stringers, some of which are molybdenite bearing. Veins and rosettes of tourmaline are also locally common. Pyrite is locally abundant. Staining with sodium cobaltinitrite solution indicates that much of the pink colour is due to the presence of potassium feldspar, although some may also be due to the hematization of feldspar. Some of the potassium feldspar is secondary and occurs along the margins of quartz veins.

Near Mo-Cu mineralization, silicification and quartz veining are very common. The pinkish colour locally predominates, but is by no means ubiquitous. Tourmaline is present locally, but is not abundant. Sulphide minerals and magnetite are disseminated throughout the rock.

Visible alteration associated with gold mineralization includes silicification, quartz veining, and weak carbonatization. Disseminated sulphide minerals (mainly pyrite) are generally closely associated with gold mineralization and tourmaline is present in most of the occurrences.

Although these alteration assemblages are present in the mineralized vein systems, similar assemblages also occur associated with apparently barren veins.

Future geochemical, petrographic, and fluid inclusion studies are planned to further characterize visible and cryptic alteration in the High Lake area.

DISCUSSION

The nature of the Cu-Mo mineralization and associated alteration is, as was earlier suggested by Davies (1965) and Pedora (1976), very similar to porphyry-style mineralization (Evans 1980). The western phase of the High Lake Stock may represent a potential source of the mineralization as suggested by Pedora (1976). Alternatively, the isolated Mo-Cu mineralization that has been reported near the margin of the western phase of the stock may result from the assimilation of pre-existing, mineralized, porphyritic granodiorite of the eastern phase of the stock. In the latter case, the western phase may be unrelated to the initial mineralizing event.

Distal, copper-poor gold mineralization may also have been originally deposited along with this porphyry-style mineralization in the eastern phase. Such distal, polymetallic, vein mineralization is known to occur with porphyry systems (Golovanov *et al.* 1986). In the High Lake area, gold mineralization and

some of the molybdenite mineralization are hosted in D_2 structures which postdate the cooling of the eastern phase of the stock. Furthermore, the presence of gold in D_2 shears within that phase and the unconformably overlying Crowduck Lake Group suggests that the present sites of mineralization are related to a significantly later event. As the western phase of the High Lake Stock is unaffected by this deformation, it is possible that the western phase of the stock acted as a heat pump, which remobilized gold and sulphide minerals from earlier sites into their present, structurally controlled sites.

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011. Detailed Lithological, Structural, and Alteration Mapping of the Cameron Lake Gold Deposit, Northwestern Ontario

D.R. Melling[1], D.H. Watkinson[2], and R.P. Taylor[2]

[1]Research Associate, Department of Geology, Carleton University, Ottawa.

[2]Professors, Department of Geology, Carleton University, Ottawa.

INTRODUCTION

The Cameron Lake Gold Deposit is located in the Kenora Mining District about 80 km southeast of the Town of Kenora (49°17'N Latitude, 93°44'W Longitude; *see* location map). The original gold showings which comprise the surface expression of the deposit were discovered in 1960 by two prospectors working for Noranda Mines Limited. Subsequently, four separate diamond-drilling programs were conducted on the property prior to the recognition of a potentially mineable deposit in 1983. Since then, drill-indicated geological reserves of 1 474 358 tonnes (1 625 202 short tons) grading 5.9 grams gold per tonne (0.16 ounce gold per ton) have been delineated above the 1300 foot level. The deposit remains open to depth (Melling *et al.* 1986). Phase 1 of underground exploration has been completed: it consisted of an inclined, 730 m (2400 foot) long ramp to the 110 m (365 foot) level; about 275 m (900 feet) of lateral development in two ore drifts and crosscuts; one short subvertical raise; and approximately 5000 m (19 000 feet) of diamond drilling on 7.5 m (25 foot) centres.

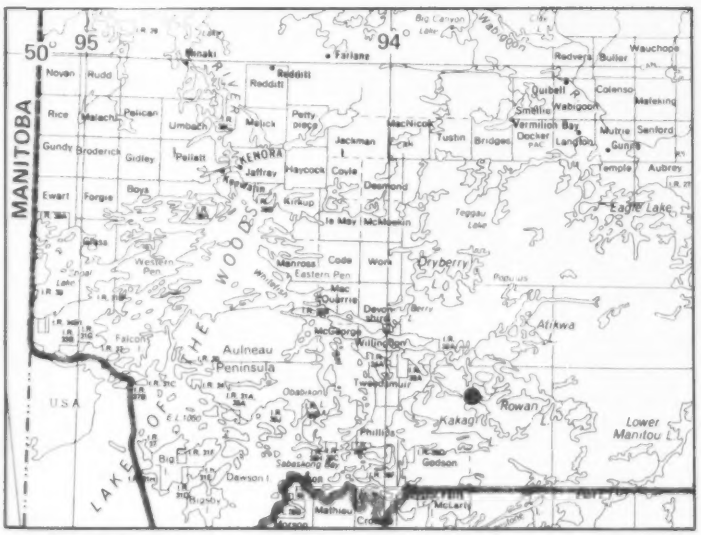
The early exploration efforts at Cameron Lake were hampered by the lack of surface exposure. The original gold showings consisted of several small, isolated outcrops, and correlation of drillhole data was difficult because very little was known about the structures controlling gold distribution and the geometry of the deposit. Since the 1983 discovery, an ongoing trenching program has created additional exposures annually. The geological information gained from detailed mapping of these exposures has been critical to the understanding of the deposit and in planning underground development.

The purposes of this report are a) to present the results of the detailed mapping to date and describe the methodology employed during mapping; and b) to highlight some of the more significant geological features and demonstrate how their recognition can be critical to a successful exploration program.

LOCAL GEOLOGY

The Cameron Lake Gold Deposit is situated about 500 m from the north shore of Cameron Lake (Figure 011.1). The property is underlain by mafic volcanic rocks and interbedded, intermediate to felsic volcanic rocks—all of the Cameron Lake Volcanic Succession. Two subconcordant mafic sills intrude the volcanics and are interpreted to be subvolcanic intrusions related to large masses of mafic to ultramafic rocks to the northwest of the property (Kaye 1973). A large, concordant, felsic porphyry sill is also present, as well as numerous thin dikes of similar composition. All rocks have been metamorphosed to greenschist-facies mineral assemblages.

The Deposit occurs within deformed basaltic rocks of the Cameron Lake Shear Zone (CLSZ), adjacent to their contact with one of the mafic intrusions (Figure 011.1). The basaltic rocks comprise roughly equal proportions of massive and pillowed flows, with less than 10 percent pillow breccia.



LOCATION MAP Scale : 1:1 584 000 or 1 inch to 25 miles

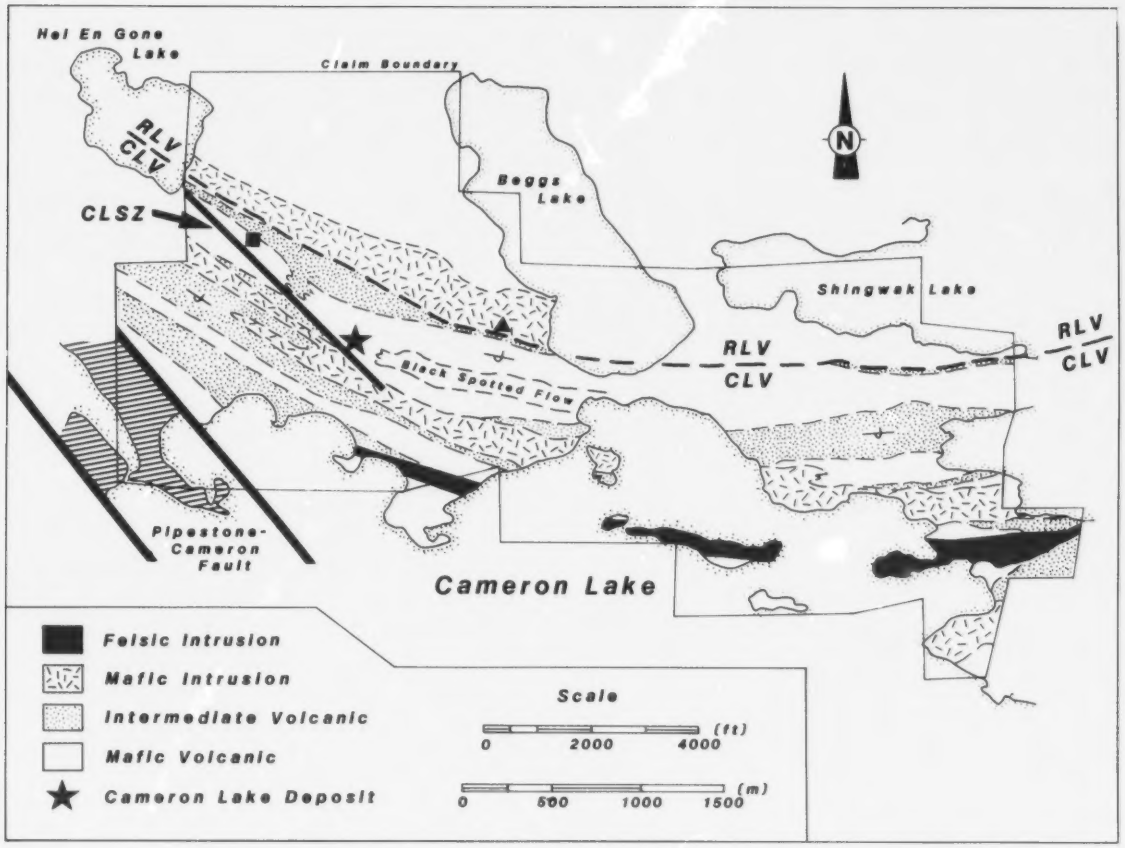


Figure 011.1. *Geology of the Cameron Lake Property. RLV = Rowan Lake Volcanic Succession, CLV = Cameron Lake Volcanic Succession, CLSZ = Cameron Lake Shear Zone.*

Coarser grained, massive flows locally have up to three percent, irregularly shaped, chloritic clots (interpreted as amygdules) which impart a distinctive, "black-spotted" texture. One "black-spotted" flow, about 130 m thick, has been traced 1.2 km east from the CLSZ, where it terminates against pillowed flows near the Deposit (Figure 011.1).

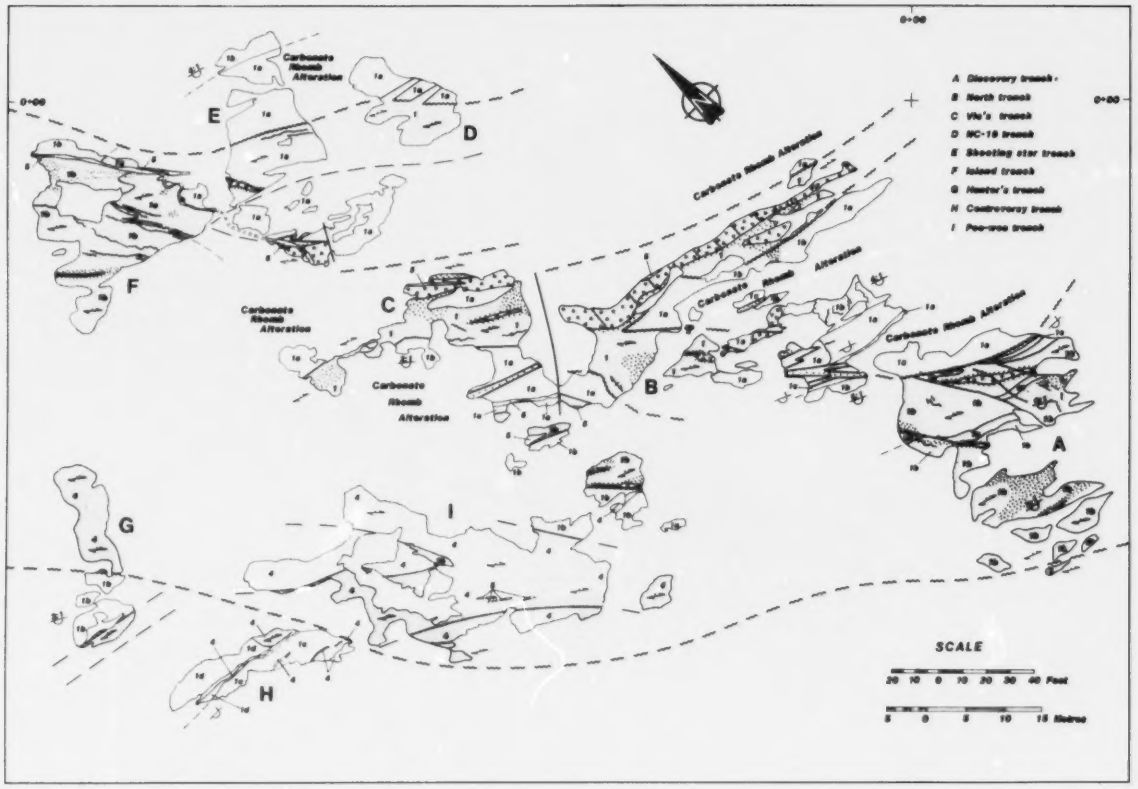
Three intermediate to felsic metavolcanic units occur on the Property (Figure 011.1). The first, marking the contact between the Rowan Lake Volcanic Succession and the overlying Cameron Lake Volcanic Succession, consists of well-bedded, pyroclastic and epiclastic rocks, and laminated, muddy, graphitic metasediments. The second unit is a distinctive lapilli-crystal tuff of intermediate composition. It is crudely bedded, monolithic, and contains as much as 50 percent euhedral feldspar laths. The third unit underlies the north shore of Cameron Lake and consists of reworked, heterolithic lapilli-tuff. This unit is bedded; however, deformation is intense due to the proximity to the Pipestone-Cameron Fault.

Discordant, quartz-feldspar-porphyry dikes several hundred metres long and 1 cm to 3 m thick have intruded the metavolcanic succession. Locally they occur within zones of shearing and are fractured, displaying a complex internal quartz-carbonate-vein network.

For more comprehensive discussions of the regional geology of the Cameron Lake and surrounding areas, the reader is referred to Melling and Watkinson (1986), Melling (in preparation) and Melling *et al.* (in preparation).

TRENCHMAPPING METHODOLOGY

The outcrops illustrated in Figure 011.2 were excavated using a variety of earth-moving equipment. During the early stages of the trenching program, a small John Deere 350 bulldozer/backhoe was employed; however, once road access to the property was established, larger equipment, including a D-7 bulldozer, was used. Overburden cover consisted primarily of glacial till, which varied in thickness from several centimetres up to about 3 m. Originally, the areas to be trenched were defined on the basis of results of shallow diamond drilling; however, during the continuing program, additional areas were selected on the basis of integrated drilling and mapping data. In all cases, test pits were dug, using the backhoe, to establish overburden thickness prior to initiation of major excavation.



5 Felsic intrusion
4 Mafic intrusion
1 Mafic volcanic rocks
1a Massive basalt
1b Pillowed basalt
1c Interflow sediment
1d Lapilli tuff

Foot 10 0 10 20 30
Metres 5 0 5 10

Cleavage attitude
Bedding overturned
Pillow topping direction
Shear zone boundary
Internal shear zone boundary
Late brittle fault

Type 1 Buckled extension vein
Type 2a Gold-bearing breccia-vein
Type 2b Ptygmatic veinlet
Type 3 Straight extension vein
Disseminated pyrite
Sheared carbonate-sericite rich rock

Figure 011.2. Detailed Surface Geology of the Ore Zone, Cameron Lake Gold Deposit. Compiled by D.R. Melling (1984 through 1987).

After the overburden was stripped, a Wajax Mark III fire pump was employed to remove the 2 to 15 cm thick veneer of loose gravel remaining on the outcrops. This was completed in two stages: the first washing removed the bulk of material remaining on the outcrops, and the second washing cleaned off the remaining sand and mud splatter, revealing lichen-free, commonly glacially polished, outcrops.

To provide accurate ground control, string grids were established over each trench. The strings were laid out at 10 foot (3 m) intervals and oriented both northward and eastward. Two strings in each direction were surveyed, using either a transit or a Brunton compass, and their orientations checked, using a Douglas protractor, at their intersection. All strings were measured, using a metal, carpenter's tape measure. In each case, the grid covering an individual trench was constructed such that some overlap with adjacent trenches occurred.

Once the string grids were established, each trench was mapped individually. Blue-line-gridded mylar, graduated in tenths of an inch, was taped to a plastic-wrapped, plywood sheet. Field mapping was conducted at 1:60 scale, and all geological features, including the outcrop outline, were mapped using a tape measure.

During mapping, emphasis was placed on the relationships between primary lithologies, structures produced by deformation, superimposed alteration and veining, and gold distribution. Colours were assigned to designate outcrop outlines, lithologies, cleavage zones, alteration types, vein types, and individual structures. Descriptive notes were written directly on the mylar.

Each individual trench map was then photomechanically reduced by 50 percent to a scale of 1:120 onto double-matte film. The results were then compiled on a single map of "manageable" size by piecing together all the individual maps, with control being afforded by mapping overlap between trenches and the blue-line grid. This product was then further reduced by 50 percent to a scale of 1:240, which is the conventional mine- and drill-section scale used in the exploration industry. Rapid comparison with drilling and underground results is therefore easily afforded. Figure 011.2 is a generalized, interpretive, 33 percent reduction of the results of trench mapping.

LITHOLOGIES

Three distinctive lithologies are recognized in trenches of the gold zone at Cameron Lake (Figure 011.2). These are mafic metavolcanics, mafic intrusive rocks, and felsic intrusive rocks.

The mafic metavolcanics comprise approximately equal proportions of interbedded, massive, and pillowed basalt with minor interflow metasediments and lapilli-tuff. Individual flows range from 3.5 to greater than 14 m in thickness. The massive flows are aphyric, fine to medium grained, and locally contain up to three percent, small, amoeboid, chlorite-filled amygdules. On the southeastern edge of an irregularly shaped portion of the North Trench (Figure 011.2), a 15 cm thick layer of flow-top breccia occurs.

The pillowed flows are aphyric and aphanitic. Distinctive chloritic selvages up to 2.5 cm thick are common, and in several localities well-formed pillows allow top determinations. Amygdules may comprise up to four percent of the pillows and locally occur in higher concentrations at the top of individual pillowed flows.

The mafic interflow metasediments are fine grained and rhythmically bedded. Individual beds are about 10 cm thick and display subtle grading. The lapilli-tuffs are feldspar phyric and show no evidence of internal stratification or grading. Based on data from drilling, these two rock types compose less than five percent of the mafic metavolcanic succession.

Data obtained from mapping the mafic metavolcanics were used to constrain the attitude of the metavolcanic succession that hosts the Deposit. Stratigraphic-younging directions were obtained primarily from the interflow metasediments and the contacts between massive and pillowed flows. All of these features are consistent, and indicate an east-striking, steeply north-dipping, overturned succession facing south (275°/70°N).

The mafic intrusive rocks are exposed along the southern part of the trenched area. They are medium grained, holocrystalline and contain plagioclase, pyroxene, and quartz. Most of the intrusive rocks are discordant to bedding in the surrounding mafic metavolcanics; however, several small associated dikes appear to be subparallel to bedding.

The felsic intrusive rocks comprise several steeply dipping dikes up to about 1.5 m thick. They are quartz- and feldspar-phyric, and appear to be continuous over significant strike lengths. They intrude both the mafic metavolcanics and the mafic intrusive rocks.

SHEAR ZONE STRUCTURE

The Cameron Lake Shear Zone (CLSZ) has been traced by exploration diamond drilling and property-scale surface mapping for more than 1000 m to Hel En Gone Lake (Figure 011.1) at the northwest boundary of the property (Melling *et al.* 1986). Based on these data, an average strike and dip of 315°/70°N and a width between 11 m and 60 m have been determined for the CLSZ. In detail, however, the shear zone consists of both anastomosing and *en echelon* shears, whose orientations are in part controlled by host rock anisotropies. The mafic intrusive rocks in the structural footwall to the deposit exert the greatest control on both the location and orientation of the shear zone in the vicinity of the Deposit. The entire contact between these rocks and the mafic metavolcanic host to the Deposit is sheared.

The CLSZ is a zone of high strain, as indicated by the pronounced flattening of primary structures such as pillows, breccia fragments, and amygdules, and intense penetrative cleavage development in aphanitic to fine-grained mafic metavolcanics, and medium-grained mafic intrusive rocks. The rocks are commonly fissile, and cleavage is defined by the planar alignment of sericite and chlorite minerals. The mean cleavage, as measured within the zone of deformation transecting the mafic metavolcanics, trends 300°/74°N; however, cleavage trends in the mafic intrusive rocks (Pee-wee trench, I, Figure 011.2) approximate that of the CLSZ (315°/70°N). The mafic intrusive rocks are the most strongly deformed rocks exposed to date.

A thin, interflow metasedimentary unit is exposed on the northeastern edge of the Discovery trench (A, Figure 011.2) near the boundary of one branch of the shear zone. This unit represents a passive marker which has been transposed into the plane of the shear zone. It is transected by a narrow zone of intense shearing and cleavage development. An apparent dextral offset of about 7 m occurs across this zone (North trench, B, Figure 011.2). In addition, two distinct massive flows interbedded with the pillowed rocks have been rotated toward the plane of shear and are also transected by narrow zones of intense shearing and cleavage development (Discovery trench, A, Figure 2). One flow exhibits an apparent dextral offset of about 3.5 m across one of these zones, and transposition of the flow is seen in the adjacent walls. Cleavage, elsewhere oblique to these narrow zones of intense shearing, becomes increasingly parallel with proximity to them. The cleavage is folded in a few locations into Z-folds, which plunge steeply toward the east (not shown on Figure 011.2).

Stretching lineations measured within the cleavage plane average 60°/052° (not shown on Figure 011.2).

A thin, continuous, felsic dike is exposed in the Island trench (F, Figure 011.2), the Shooting Star trench (E, Figure 011.2) and Vic's trench (C, Figure 011.2). This dike represents a nonpassive marker due to its competency contrast with the host mafic metavolcanics. It has remained within the field of shortening throughout the mechanical development of the shear zone, and has been buckled into a number of asymmetric Z-folds. Other smaller felsic dikes are present, several of which are boudinaged. In general, the arrays of boudins trend parallel to the overall CLSZ trend (315°). In one location, the discordance between the orientations of the individual boudins and the entire array is indicative of clockwise rotation (Pee-wee trench, I, Figure 011.2).

Strongly deformed mafic intrusive rocks occur in Hunter's trench (G, Figure 011.2) and in the Pee-wee trench (I, Figure 011.2). These rocks are structurally bounded to the north and south by mafic metavolcanics. The distribution of the mafic intrusive rocks and their contact relationships confirm the presence of a tectonic wedge or slice, which was detached from the mafic intrusive sill (Figure 011.1) during deformation. The deformed slice is up to 20 m thick and extends for about 150 m along strike and down dip. The sill itself is about 100 m thick, and, together with the detached tectonic slice, represents the fundamental control on the location and orientation of the CLSZ in the vicinity of the deposit, due to its competency contrast with the basalts.

Two late brittle faults, recently identified, occur at a high angle to both the lithologic contacts and the structural fabric. One bisects the North trench (B, Figure 011.2) and Vic's trench (C, Figure 011.2), and the other occurs at the southern edge of the Shooting Star trench (E, Figure 011.2). Both faults are characterized by one or more thin (1 cm), black, aphanitic seams across which juxtaposition of strata occurs. They trend northeast, and dip subvertically; apparent dextral offsets of several metres occur in both. In places, they truncate rock types, cleavage, alteration, and veining.

In the vicinity of the deposit, several *en echelon* and anastomosing branches collectively define the CLSZ. Three distinct en echelon branches of the shear zone are evident in Figure 011.1. The westernmost branch passes through the Island, Shooting Star, and NC-19 trenches (F, E, and D, Figure 011.2); the central branch passes through North and Vic's trenches (B and C, Figure 011.2); and the most easternmost branch branches from the Discovery trench (A, Figure 011.2). Note the similar orientations of bedding in the host metavolcanics to the Deposit. Although the mafic intrusive rocks control the overall location and orientation of the CLSZ at the property scale, bedding plane anisotropies clearly influence the orientation of several branches of the shear zone at the deposit scale.

VEINING AND ALTERATION OF THE MAFIC METAVOLCANICS AND INTRUSIVE ROCKS

Three distinct vein types are recognized in the trenches of the ore zone at Cameron Lake:

1. early, barren, extensional, quartz-carbonate veins which have been buckled
2. a major system of gold-bearing, pyritic, quartz- and albite-rich breccia veins and associated ptygmatic veinlets
3. a late group of straight, crosscutting, locally *en echelon*, extension veins which contain a quartz-carbonate-hematite-gold assemblage

The spatial distribution and orientations of these vein types are illustrated in Figure 011.2. Their mineralogy, textures, and genesis are discussed in Melling (1986) and Melling *et al.* (1986).

Three types of alteration were mapped on surface, in order of increasing proximity to the deformed, gold-bearing rocks (Figure 011.2), they are:

1. disseminated carbonate rhombs
2. pervasive carbonate±sericite
3. pervasive carbonate-sericite-pyrite

The disseminated carbonate rhomb alteration type is restricted to most chloritic mafic metavolcanics and mafic intrusive rocks outside, but adjacent to, branches of the shear zone. It is characterized by rusty-weathering carbonate euhedra up to 2 mm in size, which increase in abundance with proximity to branches of the shear zone. This type of alteration forms envelopes up to tens of metres wide in the rocks adjacent to wide, foliated, gold-bearing zones.

The pervasive carbonate±sericite alteration type is confined to the foliated mafic metavolcanics and parts of the foliated mafic intrusive rocks within branches of the shear zone (Figure 011.2). It is characterized by abundant, rusty-weathering, fine-grained carbonate with lesser, light buff to tan sericite aggregates and laminae. Chlorite is sparse (two percent) to absent. In areas of less intense deformation, flow contacts and relict pillow selvages are locally preserved. In general, the pillowed metavolcanics appear to be more susceptible to this type of alteration.

The pervasive carbonate-sericite-pyrite alteration is spatially associated with gold-bearing breccia veins which occur within branches of the shear zone (Figure 011.2). It is characterized by disseminated pyrite euhedra up to 2 mm in size in foliated, pervasive, carbonate-sericite-altered mafic metavolcanics. Pyrite occurs in highest concentrations (up to 10 percent) within and adjacent to the breccia veins. Locally, diffuse, elongate seams of disseminated pyrite occur either along the strike extension of the breccia veins or adjacent to unexposed areas, where breccia veins may be concealed. Pyrite is the principal guide to gold in the Cameron Lake Deposit. It has been demonstrated, by petrography and geochemistry, that gold is most closely associated with pyrite rather than with the more extensive carbonate alteration (Melling 1986, Melling *et al.* 1986).

DISCUSSION

The methodology employed in mapping the trenches at Cameron Lake can be applied in any situation where detailed field mapping is required. The technique allows for high levels of precision and accuracy of location to be achieved. In Figure 011.2, the

accuracy is estimated to be within a few metres over the entire map area (140 m). In an ongoing exploration program, as additional exposures are examined, string grids can be re-established and mapping overlap ensures precision. The string grids (in this example, 10 by 10 feet) force the geologist to focus on each individual block, noting features which might otherwise be overlooked during routine mapping. After mapping has been completed, grab, chip, or channel samples can be taken for analysis and located easily on the map. These samples can be obtained from individual lithologies, structures, vein types, and alteration types, and therefore delineate those geological features most closely associated with mineralization.

The information gained from surface mapping, particularly structural orientation data, is commonly not obtained from diamond drilling. An understanding of the geometry of a shear zone and the distribution of contained gold in any deposit is critical to both planning for, and interpreting data from, diamond drilling. Depending upon access and overburden thickness, the cost of a trenching program is commonly low relative to that of even a single diamond-drill hole. During the early stages of an underground exploration program, data on deposit geometry are essential for engineering and development planning.

In summary, trenching and subsequent detailed mapping are important tools for the exploration geologist, providing data that might otherwise be unavailable. They complement other exploration techniques and have the potential to reduce exploration costs, thus increasing the probability of successfully identifying and developing new mineral deposits.

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012. Stratigraphy, Structural Development and Auriferous Mineralization in the Cross Echo–Troutfly Lake Area, Northern Wabigoon Greenstone Belt, Northwestern Ontario

Lesley B. Chorlton

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

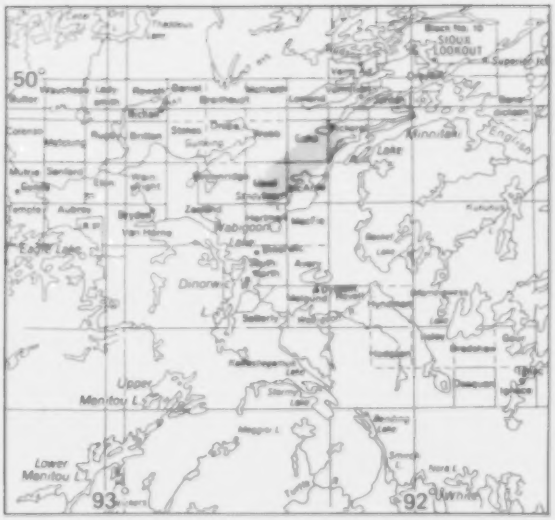
This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

The aim of this project is to determine the tectonic development of the northeastern arm of the Wabigoon Greenstone Belt south of Sioux Lookout, in particular, the relationships between the structures in the rocks and 1. their thermal history, 2. the emplacement of granitoid intrusions, and 3. hydrothermal mineralization. This report presents: 1. a summary of field relationships of the stratified rocks which are most significant to the regional structure, and 2. a current understanding of the tectonic development, particularly its role in focusing gold in the study area. This area extends southwest through the Goldlund Mine area in Echo Township to the Troutfly-Gardnar-Beartrack Lakes area in Laval Township (Figure 012.1).

Since the discovery of the Goldlund (Newlund) Mine in 1941, the area has been prospected for gold. At present, the most active exploration is being undertaken by two major interests: 1. Camreco Incorporated, which is engaged in a comprehensive geophysical survey and diamond drill program on their property and their adjoining, recently acquired, Goldlund Mines Property located east of Cross Echo Lake (The Northern Miner Press, January 12, 1987; April 27, 1987); and 2. Mistango Consolidated Resources, which is drilling two promising zones on their claim block around Troutfly Lake. West of this claim block, Camreco Incorporated holds more claims. Tarbush Lode Mining Limited have also recently explored their large claim block using geology, geophysics, and diamond drilling. Recent staking includes properties on Cross Echo Lake, adjacent to those of Camreco Incorporated and Tarbush Lode Mining Limited, and two gold occurrences on Beartrack Lake (Figure 012.1).

This project was undertaken concurrently with the regional mapping of McAree, McFie, and Avery Townships in 1986 (Berger 1986; Berger *et al.* 1987a, 1987b, 1987c), and Laval and Hartman Townships in 1987 (Berger, Article 013, this volume). In 1986, the author mapped, at 1:15 840 scale, an area centred approximately on the Goldlund Mine and extending to the southwest into northern Laval and McAree Townships, and northeastward into Pickerel Township. The emphasis of this work was upon the structural geology of the area. During the present field season, the mapping was extended to the southwest, past the Cross Echo and Gardner Lake Stocks into central Laval Township, and showings at Goldlund, Troutfly Lake, and Beartrack Lake were mapped at a more detailed scale.



LOCATION MAP

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1 inch to 25 miles

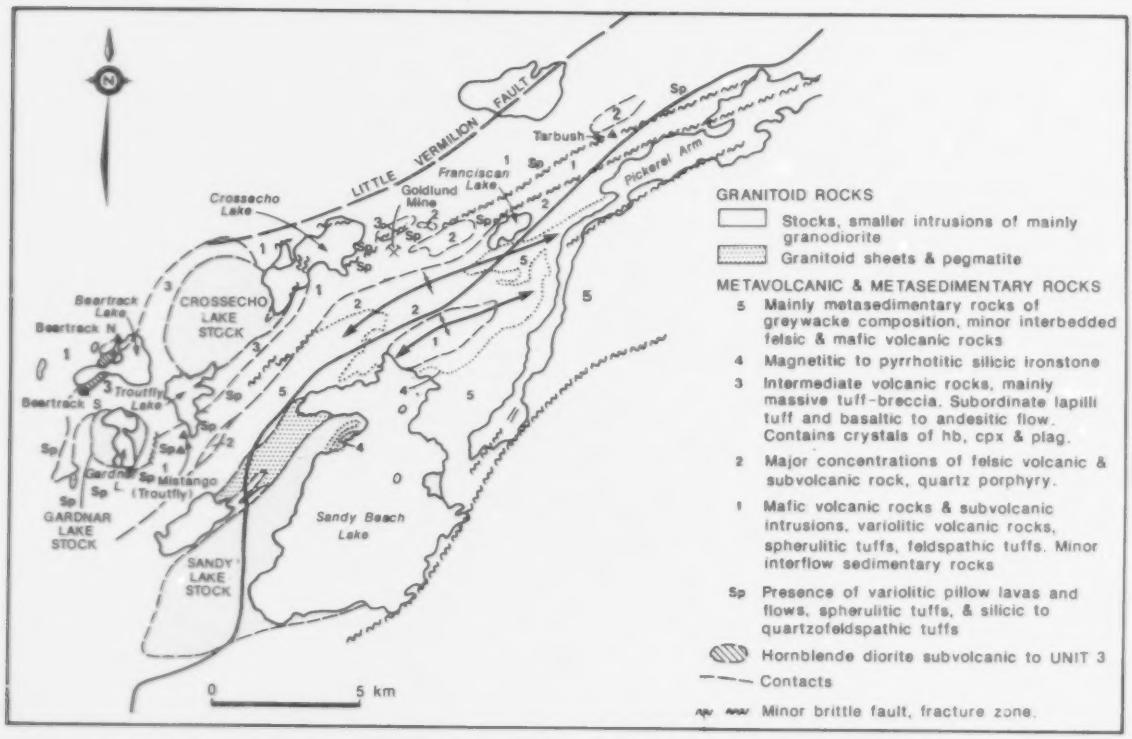

Figure 012.1. *Distribution of metavolcanic, metasedimentary and granitoid rocks in the Cross Echo-Troutfly lakes area, showing gold occurrences.*

GENERAL GEOLOGY

STRATIFIED ROCKS

Metavolcanic rocks underlie the northwestern side of the area, and metasedimentary rocks predominate in the southeastern side (Figure 012.1). The transition between volcanic and sedimentary rocks is marked in the northern part of the area by a prominent ironstone which is either sheared out or missing in the south. Younging directions, which are mainly southeast with local reversals, suggest that the metasedimentary rocks are younger than the metavolcanic rocks. This interpretation is uncertain, however, because of possible structural juxtapositioning.

The metavolcanic rocks are mafic to felsic in composition and are accompanied by subvolcanic intrusions. The mafic volcanic rocks include vesicular pillow lavas and pillow breccia, with minor interpillow chert and iron formation, laminated interflow metasedimentary rocks, and massive phaneritic flows. Felsic metavolcanic rocks consist of feldspar-phyric dacite and quartz-phyric rhyolite, and intermediate to felsic ashflow. The dacite and rhyolite are locally flowbanded, autobrecciated, or pyroclastic. The ashflow contains fragments of both felsic (dominant) and mafic metavolcanic rock, and encloses rare interbeds of pillowed metabasalt. Angular inclusions and lenses or dikes of dacitic metavolcanic rock are found together within the pillowed metabasalts in several places. Mafic and felsic volcanism may therefore have been coeval.

The mafic volcanic rocks locally develop patchy concentrations of plagioclase phenocrysts, which are centimetre scale in massive flows and millimetre scale in pillow lavas. Where plagioclase phenocrysts occur, some pillows and flows contain marginal, fine, white or buff varioles, and cores enriched in coalesced varioles, imparting a bleached appearance to the rock. Massive spherulites and well-bedded spherulitic fragmental rocks, containing intact and broken spherulite or variolite, massive rhyolite or rhyolite tuff, accretionary lapilli, and feldspar and quartz fragments, invariably occur near variolitic mafic rocks, and pass locally into more normal, quartzofeldspathic, crystal-lithic tuffs. The spherulitic tuffs occur throughout the area (Figure 012.1). Their association with the variolitic metavolcanic rocks, and distinctive lithological character make them useful as a marker horizon.

Subvolcanic, metadiabase sills vary from coarse-grained metagabbros, characterized by subophitic ferromagnesian grains and, locally, centimetre scale plagioclase phenocrysts, to medium- and fine-grained mafic rock with well-developed diabasic texture. Many can only be confidently separated from the coarse-grained, metabasalt flows where chilled margins and discordancy with the metavolcanic rocks are obvious. Titanomagnetite-rich, granophyre patches were observed in one sill, and a layer of quartz diorite gradational to more mafic, clinopyroxene-rich metadiabase was observed in another, signifying *in situ* differentiation. Paler weathering, more feld-

spathic sills, locally display both mafic and felsic chilled contacts, gradation into more mafic metadiabase, and, rarely, rhythmic layering. These sills occur from the Goldlund Mine area through the Troutfly Lake (Mistango) Prospect to the southeast of Gardner Lake. Where fractured or veined, these metadiorites host some of the most significant known gold mineralization. Variolitic mafic flows and spherulitic tuffs accompany these metadioritic sills along the southeastern side of the area. It is speculated that the flows and tuffs may be genetically related to the sills.

This predominantly bimodal metavolcanic suite passes gradationally, although relatively abruptly, into a suite dominated by coarse pyroclastic rocks of an overall intermediate composition. Coarse-grained, plagioclase-rich, basaltic and andesitic flows span the transition, especially between Cross Echo and Troutfly Lakes, and in the north Gardnar-Beartrack Lakes area. The main rock types are: a. tuff-breccias containing fragments of feldspar-phyric dacite; b. feldspar-phyric to very coarse grained metabasalt and andesite; c. hornblende- and possibly clinopyroxene-phyric andesite and/or basalt; d. bleached, vesicular, variole-rich metabasalt; e. aphyric felsite; and f. iron formation. At Beartrack Lake, these rocks are accompanied by a subvolcanic intrusion of hornblende-rich diorite. The nearly ubiquitous presence of coarse, originally euhedral (now deformed) hornblende and clinopyroxene crystals in this suite of rocks provided a criterion for separation of the two metavolcanic assemblages in the field.

The distribution pattern (Figure 012.1), and the field relationships among the metavolcanic rocks (i.e. chips of iron formation, basalt, and feldspar-phyric dacite of one suite in the pyroclastic rocks of the other), suggest a regional younging into the centre of the metavolcanic belt and a gentle regional dip envelope overall.

The metasedimentary rocks consist mainly of metawackes grading locally into more feldspathic siltstones and sandstones. Lenses of felsic ashflow are exposed locally along Pickerel Arm. Mafic dikes and lenses, now amphibolitic, and mafic clasts in the ashflow, suggest that volcanism during the deposition of the metasedimentary rocks may have been both mafic and felsic. Biotite-plagioclase-quartz ± amphibole assemblages predominate in the metawackes, and andalusite and pinhead garnet are also common over the southern half of the area. Staurolite and cordierite porphyroblasts appear near the Sandybeach Lake Stock. Pyrrhotite-enriched beds of metawacke are common around Sandybeach Lake. Amphibole-epidote-plagioclase-quartz ± biotite ± garnet assemblages characterize the amphibolites.

Sedimentary ironstone occurs between the felsic ashflow of the metavolcanic terrain and the metawacke sequence. The ironstone is well-bedded and silicic, with massive and laminated beds from one to tens of centimetres thick, composed predominantly of granular, recrystallized quartz. Interbeds of intraformational breccia are composed of tablets of this silicic rock in a dark, magnetite-rich matrix. The ironstone is predominantly pyrrhotitic and pyritic in some places, and magnetitic in others. Sulphide minerals generally occur as pod-like concentrations and segregations along, and overprinting foliation planes. Magnetite, however, is disseminated and enriched in certain beds, particularly in the matrix of the intraformational breccia. Where sulphide minerals occur in the ironstone, they are also present in the adjacent ashflow. The magnetite may owe its presence to synsedimentary iron-enrichment, whereas the sulphide mineralization, which is not clearly stratabound, may be secondary, perhaps resulting from metasomatism during deformation. Refolded folds and mylonitic textures in the polyphase fold hinges indicate substantial strain; possibly sheared and flexed contacts have helped to focus sulphide.

The pattern defined by the iron formation at the contact between the metavolcanic rocks and the metasedimentary rocks outlines a partially closed dome and basin structural pattern (Figure 012.1). This would result if an early, gently or moderately dipping layering were later deformed, either by single stage vertical doming, or by upright cross folding.

GRANITOID INTRUSIONS

The Cross Echo and Gardnar Lake Stocks are tonalitic to granodioritic in composition, with less than 10% ferromagnesian minerals, mainly biotite with subordinate hornblende. Both stocks are characterized by medium- to coarse-grained bipyramidal quartz phenocrysts (0.5 to several centimetres in size) in some areas. Microcline is variable in proportion and interstitial to plagioclase. Both stocks locally display internal foliations concentric to their margins, and narrow contact metamorphic/strain aureoles of amphibolitic metavolcanic rock. Aplite dikes are abundant.

The Sandybeach Lake Stock, also mainly tonalitic to granodioritic, is more mafic than the Cross Echo and Gardnar Lake Stocks. Microcline is interstitial or poikiloblastic, and more abundant in the northern lobe on Sandybeach Lake, where the rock locally becomes quartz syenitic. Ferromagnesian minerals, mainly hornblende, constitute up to 25% of the rock, and define linear and plano-linear fabrics. Pegmatite and aplite dikes are common in the north. The thermal aureole of the stock is broad, over 2 km in apparent width on its northern side.

Feldspar porphyry and quartz-feldspar porphyry dikes are common throughout the study area, and were emplaced into both the metavolcanic-dominated and metasedimentary-dominated terrains. Some of the feldspar porphyry dikes resemble the feldspar-phyric dacites in the metavolcanic suite, and may be synvolcanic. Quartz-feldspar porphyry dikes with coarse, bipyramidal, quartz phenocrysts, up to a few centimetres in diameter, are numerous around the Goldlund Mine, Cross Echo Lake, and the eastern margin of the Gardnar Lake Stock. In the latter area, the dikes are nearly undeformed, in contrast to their highly deformed hosts. Similar quartz phenocrysts were observed in nearby parts of the Cross Echo and Gardnar Lake Stocks. There are probably two ages of porphyry dikes; the younger equivalent to the Cross Echo and Gardnar Lake Stocks, and the older equivalent to the host metavolcanic rocks.

A fourth granitoid rock type was observed as dikes and irregular pods throughout the terrain northwest and west of Beartrack Lake. These small intrusions consist of a fine-grained intergrowth of over 60% plagioclase laths, with interstitial chlorite and minor quartz. They are commonly carbonatized and sericitized, and surrounded by bleached haloes up to tens of centimetres wide. Tuffisites, with granitoid breccia pieces in either chloritic or tourmaliniferous matrices, were observed inside several of the pods. Tourmaline is exceptionally profuse, filling numerous fractures that locally are up to 25 cm wide, and densely overprinting the granitoid rock beyond the margins of fractures. Pyrite is locally common. Sparse, disseminated scheelite was detected in a few samples with an ultraviolet lamp.

These granitoid injections are more widespread than originally thought. Minor, texturally similar, highly altered (carbonatized and pyritized), fine-grained granitoid rock is exposed as fracture fillings in brecciated metadiabase or massive metabasalt along the north side of the No.1 Zone of the Goldlund Mine. Similar granitoid dikes were also recognized at the south end of Pickerel Arm.

STRUCTURAL DEVELOPMENT

Deformational imprints in the study area are assigned to two regional structural events, which were separated by the emplacement of the granitoid stocks. The earlier event, possibly thrust-related, resulted in generally moderate to gentle southerly dips of foliation and bedding, along with gently dipping zones of very strong schistosity. Some of the regional strain, involving superposition of contact thermal/strain aureoles, reorientation of early fabrics outside these aureoles, and possibly lineation development, was incurred during granitoid emplacement. The second event involved steepening of earlier fabrics, folding, fracturing, and activity along steep shear zones. This event is interpreted to be the result of northwest-southeast shortening around the granitoid stocks combined with sinistral oblique-slip. Gold mineralization accompanied fracturing and veining associated with second deformation folds and shear zones, which vary in style and attitude with position relative to the granitoid stocks.

The earliest event (D_1) involved the formation of a strong regional foliation (S_1), which, although later deformed, conforms regionally to a gentle to moderate dip envelope similar to that shown by stratigraphic contacts. It dips moderately to gently where it is best preserved, between the Cross Echo and Gardnar Lake Stocks, and in the partially enclosed domal structure defined by the metasedimentary-metavolcanic contact and ironstone marker north of the Sandybeach Lake Stock (Figure 012.2). Elsewhere, it was strongly transposed into steep attitudes during the second event (D_2), and the early foliation may be so nearly parallel to the second foliation that the difference is detected only in narrow structural panels that preserve the hinges of tight F_2 folds in S_1.

In most exposures of bedded metasedimentary rocks in the study area, S_1 strikes counterclockwise and dips nearly parallel to bedding planes, which face mainly southeast and upwards on this foliation. F_1 fold hinges are rarely seen except in the ironstone. Reconnaissance in Hartman Township has revealed steeply dipping, bedded metasedimentary rocks which young to the south and face downwards on a gently north-dipping S_1 foliation. The simplest explanation of the overturning on shallow foliations and the large tract of upward facing strata is large-amplitude D_1 thrusting.

The S_1 foliation in metavolcanic rocks, which are also upright, is developed inhomogeneously, and commonly is focused along contacts and in fine-grained, fragmental rocks. However, this foliation is particularly intense, even locally phyllonitic or mylonitic, in all units between Troutfly Lake and the Gardnar Lake Stock. The dips of S_1 in parts of this area are less than 35° to the south and southeast. In the terrain between the south parts of Troutfly and Gardnar Lakes, these shallow schistose zones in both tuff-breccia ("upper volcanic unit") and a metadiabase sill-metavolcanic rock complex ("lower volcanic unit") dip southeastward from the "younger" into the "older" unit, compatible with thrusting as a mechanism for first deformational imprint. However, because the contact probably resulted from pyroclastic processes, which are prone to unconformity, this is not necessarily diagnostic.

The second deformation (D_2) was responsible for: a. upright folds of the earlier foliation and bedding; b. a local, northeast-striking, steeply dipping crenulation or spaced fracture cleavage; c. steep ductile shear zones; and d. fracturing, on several scales. The large scale, doubly plunging antiform and synform, outlined by the map pattern and early foliations referred to above, are products of D_2. The antiform-synform pair resulted from regional northwest-southeast shortening. The doubly plunging fold hinge and lineation pattern may reflect curvature that is convex upward and to the northwest (about a northwest-southeast axis). This curvature may, in turn, be related to the larger scale regional curvature that is responsible for the doubly plunging, D_2, Lateral Lake antiform that occurs northwest of the Little Vermilion Fault (Figure 012.2). Open crenulations, and open to moderately tight, megascopic, Z-, S-, and M-folds in pre-D_2 foliations were developed in many parts of the area. The symmetry of these folds depends predominantly on the attitude of the early foliation (Figure 012.2), which formed pre-D_2, and after emplacement of the granitoid rocks. Where intrusive or stratigraphic contacts are inclined to S_1, F_2 folds of contacts and foliations may contrast in symmetry.

Schistose zones related to D_2 fall into two general categories: 1. a major set of steeply dipping, sericitic, relatively fine-grained, schistose zones, and 2. a subordinate set of east-northeasterly to southeasterly striking, schistose zones. Schistose zones of

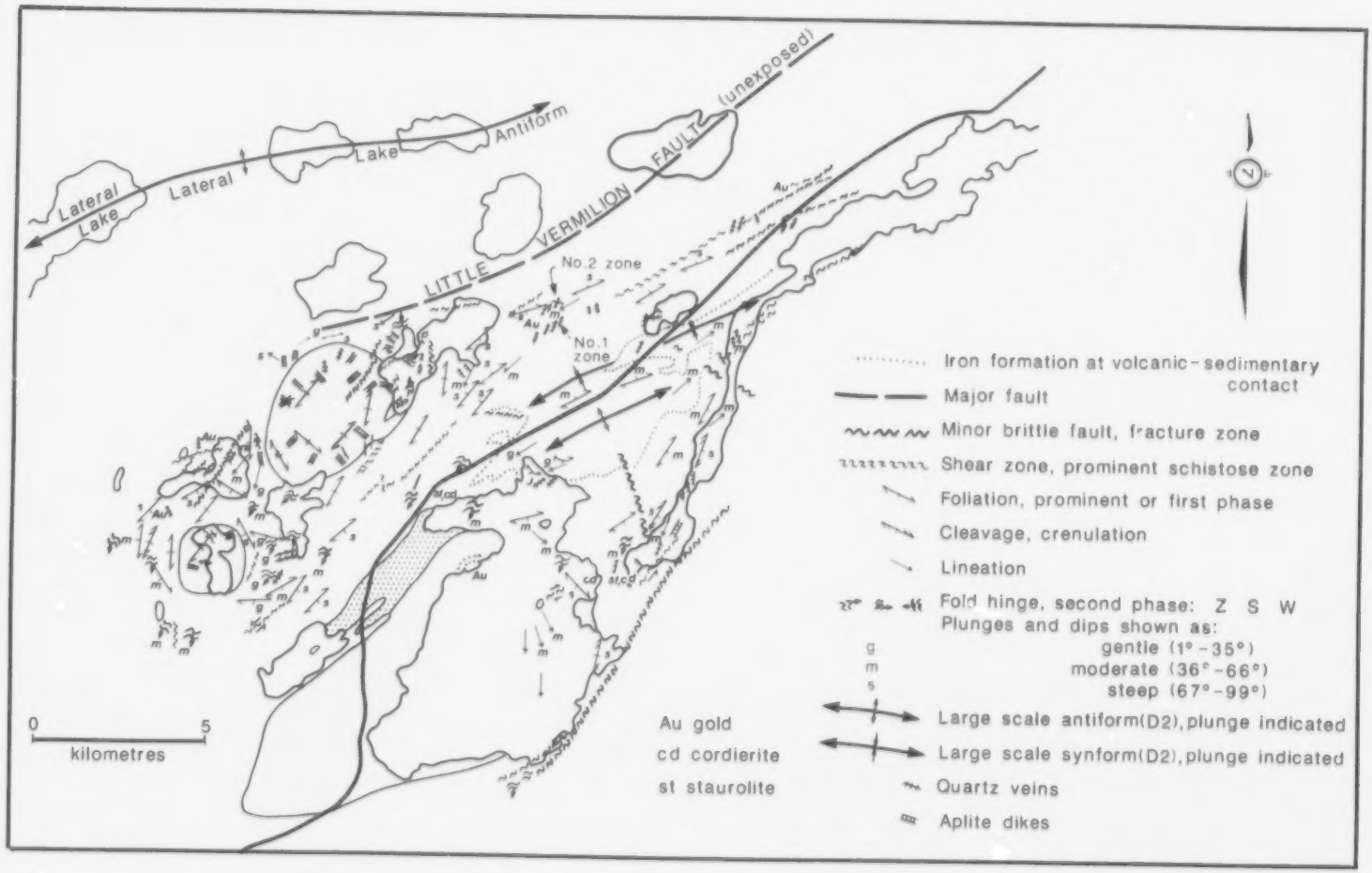

Figure 012.2. *Pre-D2 fabrics, and D2 shear zones, veins and folds of foliation in the Cross Echo-Troutfly Lakes area.*

the major set are metres to tens of metres wide, and are located where the regional foliations are steep in the limbs of D_2 folds and in the axial zones of D_2 folds; and in secondary, narrow shear fracture zones counterclockwise to the main tectonic grain. Schistose zones of the subordinate set are narrower, and in places are accompanied by a similarly-oriented crenulation cleavage. Because of the existence of locally intense, pre-D_2 fabrics, a sense of simple shear (where simple shear was operative) is ambiguous in most of these zones. Fine-grained, schistose zones in the axial planes of D_2 folds are probably essentially irrotational. However, exposures showing sinistrally-rotated plagioclase porphyroclasts, and sinistral sets of quartz-filled, *en echelon*, extension gashes occur in several of the more prominent northeasterly trending schistose zones in the metavolcanic and metadiabasic terrane. Sigmoidal and over-rotated quartz veins in phyllonitic zones in the metasedimentary terrane along Pickerel Arm (Figure 012.2) also suggest a sinistral sense for the predominant, northeasterly striking set.

Quartz- and tourmaline-quartz-filled fractures are abundant throughout the entire study area, including the granitoid stocks. They were emplaced both between and within rocks affected by D_2 simple shear. In the first setting, they are steep and northwest-to north-northwest-trending, and subperpendicular to the overall northeasterly tectonic grain of the belt. These fractures may be interpreted as normal extension fractures, reflecting an overall northeasterly extension and/or northwest-southeast shortening. Minor veinlets, with no strain implications, are also found filling the early foliations in micaceous bands in the metasedimentary schists. In the second setting, northeasterly striking *en echelon* veins, locally sigmoidal, are acutely counterclockwise to the steep, northeasterly striking, D_2 foliations and transposed lithological contacts in zones affected by D_2 simple shear, particularly from the Goldlund Mine area northeastward, and along Pickerel Arm (Figure 012.2). These veins provide the strongest evidence for a late stage component of sinistral simple shear.

Quartz veins at the Mistango property on Troutfly Lake south of the Cross Echo Stock have an entirely different geometry. These veins occur as a conjugate set, the predominant orientation being moderately north-dipping and west- to west-northwest-striking, acutely clockwise to S_2 cleavages and axial planes of the gently southwest-plunging, monoformal, F_2 Z-folds (approximately 030°/steep). The subordinate set is steeply dipping, and subparallel to S_2. The northerly dips of the main vein set may reflect either a north-side-up shear component or south-over-north rotation of the foliated metadiorite in F_2 fold hinges. The predominant vein orientation suggests a dextral shear component during D_2 in this area, although the siting and overall geometry of the stockwork probably relate to the folding.

Penetrative lineations, defined by elongated spherulites, vesicles, amygdules, and mineral aggregates replacing igneous plagioclase and hornblende or other mafic phenocrysts, are also locally prominent. The mineral aggregates are compatible with peak metamorphic assemblages. Between Troutfly and Gardnar Lakes, lineations are commonly crenulated by F_2, the lineations plunging gently northeast, and the crenulation axes plunging gently southwest. From Cross Echo Lake to Pickerel Arm, lineations change in plunge from southwest in the south to northeast in the north (Figure 012.2), consistent with D_2 flexing of fold hinges. These lineations were thus affected, and perhaps enhanced, by D_2, but were initiated prior to it, possibly during emplacement of the granitoid stocks.

Non-penetrative, subvertical, stretch (carbonatized necked plagioclase) and mineral (tourmaline, actinolite) lineations locally affect D_2-fragmented apophyses of the Cross Echo Stock north of Cross Echo Lake, and some of the schistose zones in the northwestern and northeastern parts of the study area. The lineations may reflect localized vertical extension, axial constriction, or dip-slip displacement during this carbonatization and tourmaline alteration.

Structures associated with the granitoid stocks are of two generations: the earlier relates to their emplacement and the later relates to the regional D_2 deformation. The Cross Echo and Gardnar Lake Stocks display inhomogeneneously developed, internal foliations, defined by biotite books and flattened, recrystallized quartz domains concentric to their margins, and narrow, very highly foliated contact metamorphic aureoles which dip steeply (Figure 012.2). The earlier foliations of the metavolcanic terrane dip away from the contact strain aureoles, suggesting a moderate reorientation of the D_1 structures due to the punching upward of the stocks. The fabric-forming biotite is fresh, except in the highly deformed, shear-displaced, northeastern segment of the Cross Echo Stock, and along the western side of the Gardnar Lake Stock, where chlorite and epidote replace both biotite and hornblende. Aplite dikes and subordinate, quartz-filled fractures cut the internal foliation at high angles, and are most numerous in areas of most intense foliation. They are unfoliated within the stocks, except in the sheared northeastern segment of the Cross Echo Stock and west of the Gardnar Lake Stock (above), and are openly buckled across northeast-trending axial planes outside the stocks. The weak buckling and localized foliation of the aplites are compatible with the D_2 deformation pattern.

The core of the Sandybeach Lake Stock possesses a south-plunging, linear fabric which is defined by hornblende. This linear fabric changes outward into a plano-linear fabric around the margins of the stock. The large size and general concordance with regional fabrics of the Sandybeach Lake Stock make it difficult to assess the influence of its emplacement on structures in the surrounding rocks. However, the stock is clearly affected by D_2 shear zones along its eastern side.

METAMORPHISM AND REGIONAL ALTERATION

A regional metamorphic peak in the upper greenschist facies (above the biotite isograd) was attained after the first deformation throughout most of the study area. This metamorphic peak overlapped the second deformation. Rocks metamorphosed to lower than biotite grade are located only in the extreme

northeast. The metamorphic grade increases gradually toward the Sandybeach Lake Stock, through lower amphibolite facies (andalusite-garnet-biotite in pelitic schists), to higher grade rocks containing porphyroblasts of cordierite and staurolite, and ultimately to migmatite veining in agmatite enclaves next to the contact. The Cross Echo and Gardnar Lakes Stocks, even though they possess narrow contact zones of highly foliated amphibolite, have little effect on the regional isograd pattern.

Most of the evidence for the timing of the metamorphic peak comes from the medium- to high-grade metasedimentary rocks, and suggests that peak metamorphic temperatures were achieved after D_1, prior to and overlapping D_2. First, tonalitic segregations of the migmatite enclaves were clearly folded and foliated by D_2. Secondly, both andalusite and staurolite porphyroblasts overprint S_1 and form augen within the D_2 crenulation. Coarse cordierite most commonly forms ragged, anhedral porphyroblasts which conform to the crenulated geometry of the F_2 folds and crinkles of S_1 in the host rock, and thus crystallized either during or after D_2. Comparatively fine-grained porphyroblasts of cordierite immediately next to the stock are euhedral, and form augen in the S_2 foliation. Staurolite in one outcrop area, and cordierite in another, also form monomineralic concentrations next to both quartz-filled and quartz-poor fractures cutting across, and locally axial planar to, F_2 folds. Metamorphic conditions must have remained within the stability limits of these two minerals, and the hosts were metasomatically altered from normal pelitic compositions into alkali- and silica-depleted ones next to the fractures during D_2. Both staurolite and cordierite are commonly replaced by white mica and calcite, as is the more widespread andalusite, suggesting late or post-D_2 rehydration and carbonatization (below).

Two forms of hydrothermal alteration are inhomogeneously developed but regionally pervasive: 1. disseminated calcite-magnetite, or, locally, sericite-calcite replacement, and 2. more focused tourmaline replacement. It is suspected that these alteration effects occurred under near peak metamorphic conditions, but post-dated the initial crystallization of regional metamorphic assemblages.

The calcite-magnetite replacement is the most widespread regional alteration, preferentially affecting mafic and intermediate rocks. The more feldspathic phases of the metadiabase-diorite suite and the spherulitic tuffs are particularly susceptible, as are rocks in which either early (S_1) or later (S_2) foliation is particularly strong. The northeast-striking, D_2 shear zones on either side of the Sandybeach Lake Stock are likewise converted to calcite-sericite-biotite schists in the southern and central parts of the area, and to ankerite-sericite-chlorite schists at the extreme northeastern end of the area, where the ambient metamorphic grade is lower and biotite is lacking in the surrounding metasedimentary schists. Ankerite is elsewhere confined to mineralized zones.

All zones of weakness, such as areas of strong foliation, pillow selvages or pillow breccia, scoriaceous fragments, and small mafic chips, are local foci for tourmaline replacement. Tourmaline needles radiate from replacement aggregates into the surrounding rock. However, the tourmaline is commonly aligned preferentially along S_2 cleavage or crenulation planes, or concentrated in clots along prominent D_2 schistose zones, suggesting a D_2, or younger, age. Breccia pods and dikes with tourmaliniferous matrices are particularly common within the fine-grained pods of tonalite, north and west of Beartrack Lake. Tourmaline is common in the regional quartz veins, and fills some of the latest generation of fractures which crosscut the Gardnar and Cross Echo Lakes Stocks and feldspar-quartz porphyry dikes, also suggesting a late introduction.

Other forms of alteration, such as iron carbonatization, silicification, sericitization, and albitization, are associated with sulphide mineralization in rocks with high gold potential. It is noteworthy that Giddings (1986) has concluded that the early stages of this alteration at the Goldlund Mine took place under relatively high temperature conditions, compatible with the regional metamorphic peak temperatures preceding and overlapping D_2.

GOLD OCCURRENCES

The gold occurrences described below are located in three separate areas of the belt: 1. the Goldlund-Camreco Occurrences east of Cross Echo Lake; 2. the Mistango Occurrences near Troutfly Lake; and 3. two separate occurrences near Beartrack Lake, here termed "Beartrack S" and "Beartrack N" (Figure 012.1).

The gold mineralization throughout the area is synchronous with the later stages of D_2 deformation. The differences in geometrical characteristics of each group of occurrences relate to their position relative to the Cross Echo Lake and Gardnar Lake Stocks, and the regional forces active during D_2, which produced both northwest-southeast shortening (conjugate schistose zones, conjugate and normal extension fractures, and folding) and mainly sinistral oblique-slip (northeasterly striking shear zones, and *en echelon* fracture and vein sets). Until a comparison of the age(s) of granitoid emplacement to the age of the second deformation can be made, there is no direct evidence to link the mineralization with late pneumatolytic activity of the stocks, even though such a link is possible.

GOLDLUND MINES–CAMRECO INCORPORATED OCCURRENCES

All of the metavolcanic and subvolcanic rocks described in this report are present on the combined Goldlund Mines-Camreco Incorporated property. Gold mineralization is sited preferentially in metadiorite and metadiabase intrusions, and in feldspar-quartz porphyry dikes, where they are fractured and veined with quartz and quartz-carbonate. The veins show narrow to broad alteration haloes, characterized by ankerite, calcite, ilmenite, and pyrite, with local gold and telluride minerals. The reader is referred to Webb (1948), Armstrong (1951), Chisholm (1951), Frohberg (1952), and Giddings (1986) for excellent documentations of the ore, alteration, and host rock types. During this study, attention was focused on two of the five mineralized zones outlined during early de-

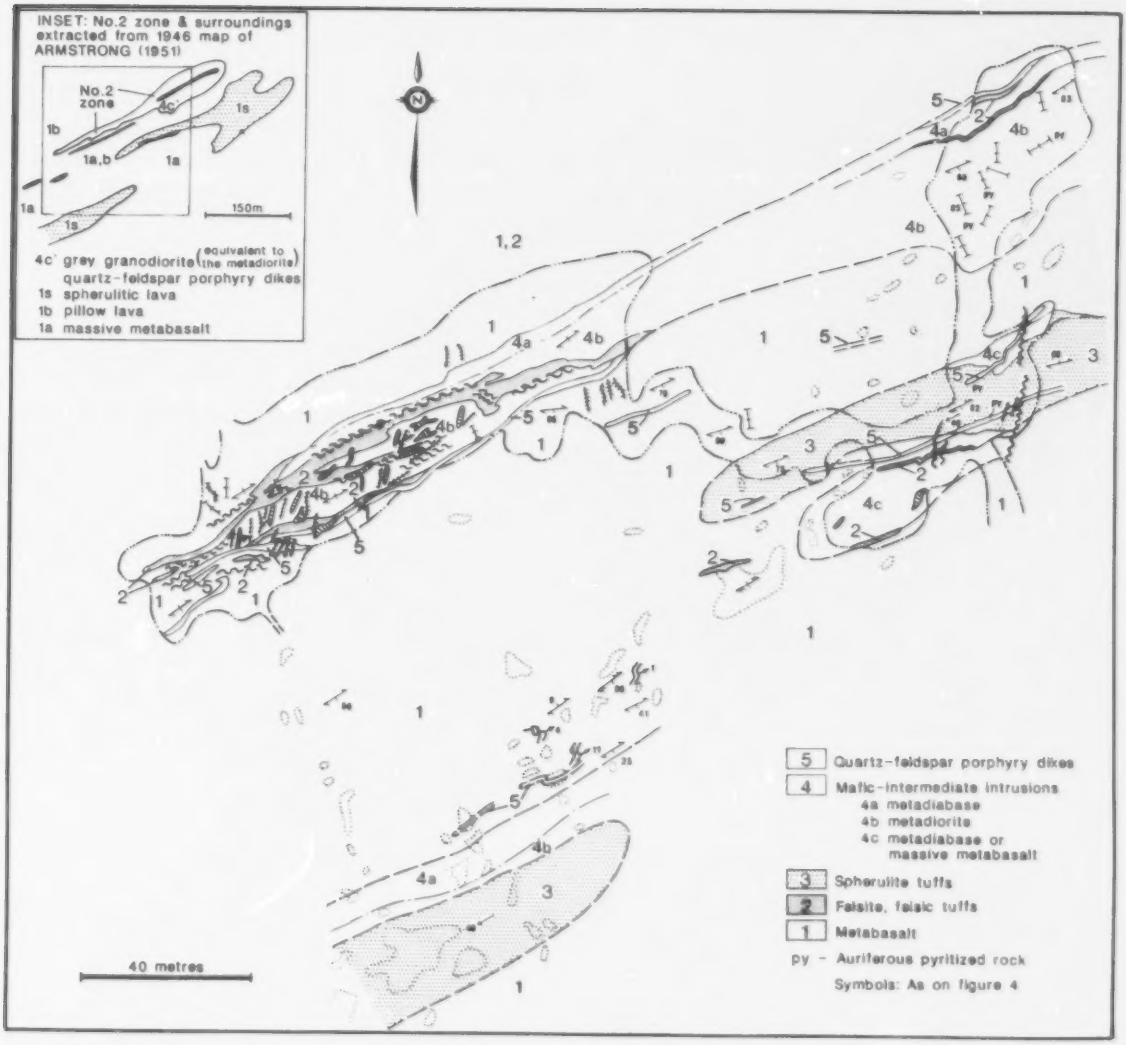

Figure 012.3. *Geology of the No. 2 zone, Goldlund Mines area.*

velopment (Armstrong 1951): the No.1 zone (Figure 012.2), which extends northeastward for over 1000 m, is hosted by the metadiorite-metadiabase complex and is the site of the underground mine and open pit, and the No.2 zone (Figure 012.2), which trends northeastward for over 260 m, and is sited mainly in metadiorite.

The intrusive rocks of the No.1 zone are affected by a weak to moderate, steeply dipping, northeast-striking foliation, and contain only minor shear zones, although faulting in them has been reported from underground workings. Most of the deformation takes the form of closely spaced, transverse fractures which site quartz veins. They form a regularly spaced set striking approximately 065° northeast, but become more clustered as the zone dies out to the east (Figure 058.3 *in* Chorlton 1986). Individual veins of the set strike 195 to 200°, and dip moderately to the north (Photo 058.1 *in* Chorlton 1986). The structural geometry here suggests a steeply dipping zone of brittle-ductile deformation, dominated by sinistral (and probably northside-up) rotation across the steep northeasterly metadiorite-metadiabase intrusion.

Three bulldozed clearings expose the No.2 zone (Figure 012.3), which is located across a ridge to the north of the No.1 zone (Figure 012.2). The most significant mineralization is again hosted by inhomogeneously altered and veined, fine-grained metadiorite, which cuts massive, pillowed, and pillow-brecciated metabasalt, locally containing varioles and narrow felsite lenses, and both spherulitic and crystal-lithic tuffs, all cut by quartz-feldspar porphyry dikes (Figure 012.3). The metadiorite passes gradationally into more mafic metadiabase along its north side in the western clearing and in another band south of the clearings, but is separated from the

metadiabase by a screen or sliver of felsite in the northeastern clearing, suggesting multiple intrusion.

Unlike the No.1 zone, the map pattern of the No.2 zone refutes the existence of simple, steeply dipping stratigraphic and intrusive contacts (Figure 012.3). The main metadiorite-metadiabase body pinches out in a series of schistose zones at the western end of the clearings, and is locally highly foliated. Felsite and felsic tuffs, previously foliated, appear to be tightly infolded in the western end of the metadiorite. Quartz-feldspar porphyry dikes are also folded. The band of spherulitic tuffs through the southeastern clearing was traced east of the clearing, but terminates abruptly against metabasalt to the west, although the same spherulitic tuffs reappear 80 m to the south as an eastward-terminating band that extends to the southwest for over a kilometre (Figure 012.3). This feature was also noted, without explanation, by Armstrong (1951) and other mine geologists (*see* Inset, Figure 012.3). The presence of gently northeast-plunging, F_2, antiformal folds of early schistosity between the southern and northern spherulite bands suggests that the explanation for the spherulite distribution, and the felsic metavolcanic rocks folded into the metadiorite, is upright folding of previously less inclined fabrics and contacts during D_2. Tightly compressed D_2 fold hinges may be sited along the width of the ridge between the No. 1 and the Nos. 2 and 3 zones, explaining the surface repetition of the spherulitic marker shown on most maps of the mine area.

The significant auriferous mineralization in the No. 2 zone consists of highly fractured, heavily carbonatized, pyritized, and possibly albitized patches in metadiorite, with few quartz veins, in the eastern clearing, and equally altered metadiorite associated with numerous quartz veins concentrated at its western extremity in the western clearing (Figure 012.3). The predominant vein orientation is steep and acutely counterclockwise to the D_2 structural grain. This orientation, and the sigmoidal traces of many of the small veins and fractures, indicate a component of sinistral rotation. However, other veins cross the main set, or dip very gently, or are sited along the northeast-trending schistose zones. The distribution and geometry of the veins is, therefore, uneven and irregular, and their concentration at the highly deformed southwestern tip of the metadiorite body is suggestive of boudinage. Fracturing in the core of the boudinaged body may have been all that was necessary to permit hydrothermal alteration in the northeastern exposure.

Three possibilities suggested by the detailed mapping of the No. 2 zone should be considered in exploring this and the surrounding area for the mineralized metadiorite: 1. that the intrusion was not originally upright, with steep margins; 2. that it too may lie in part of a tightly compressed, perhaps detached, D_2 fold hinge; and 3. that it might have been boudinaged along a sheared limb or hinge zone, during combined D_2 shortening and sinistral rotation.

MISTANGO (TROUTFLY LAKE) OCCURRENCES

The Mistango Property at Troutfly Lake exposes mainly pillowed and massive metabasalts, including those containing varioles and feldspar phenocrysts, spherulitic tuffs, and numerous subvolcanic metadiabase and metadiorite sills that are slightly discordant to the volcanic stratigraphy. The S_1 foliation is prominent, commonly moderately to gently dipping, and conspicuously folded about gently southwest-plunging F_2 monoforms. It is crosscut by a second S_2 fracture cleavage, which strikes about 030°, dips steeply, and is axial planar to the F_2 folds. The regional calcite-magnetite alteration is locally profuse in this region, particularly in very schistose rocks and in the lighter coloured metadiorite sills.

Auriferous mineralization occurs in fine-grained metadiorite, where it has been fractured and pyritized, at the expense of magnetite, commonly in the presence of quartz veins. The quartz veins (Figure 012.4) strike mainly about 260°, clockwise to the S_2 foliation, and dip moderately north, with subordinate cross veins striking about 030°, parallel to F_2 axial planes and S_2 cleavage. The most auriferous rocks are pink or buff on fresh surfaces, due to iron-rich carbonate, albite, and pyrite alteration, contrasting with the light grey colour of the same rock type away from mineralization. The veining which accompanies the disseminated pyrite and pink alteration on surface is located in F_2 hinge zones (*see* cross section, Figure 012.4). A similar structural setting was found for surface sulphide mineralization and profuse fracturing and veining of metadiorite or metadiabase in a second, parallel horizon to the south-southwest of this discovery zone.

Near the southwest clearing, the metadiorite sill is chilled against mafic metavolcanic rocks which separate it from one of the mafic metadiabases, indicating that the metadiorite and metadiabase here are separate intrusions. The metadiabase continues along the southern side of the discovery zone through an island at the southern end of Troutfly Lake, where old trenches expose several quartz-carbonate veins. The veins are surrounded by a halo of highly calcified metadiabase containing galena and pyrite. This showing also shows gold potential in one of the more mafic sills.

BEARTRACK LAKE OCCURRENCES

At Beartrack Lake, the metavolcanic rocks are cut by an irregular body of hornblende metadiorite (Figure 012.1), which is in turn cut by small injections of very fine grained tonalite. Several steeply dipping, northeasterly striking schistose zones pass through the centre of the lake, and affect the southwestern end of the metadiorite. A subordinate set of east-northeasterly striking schistose zones appears on the western side of the lake, and is present in "Beartrack S" and Beartrack N" Occurrences, predominating in the latter.

The "Beartrack S" Occurrence is hosted within the metadiorite body, which is heavily overprinted by the calcite and chlorite alteration, near its southern contact with pyroclastic rocks. Two mineralized exposures were obvious on surface when the occurrence was visited during the Summer of 1987. The northern

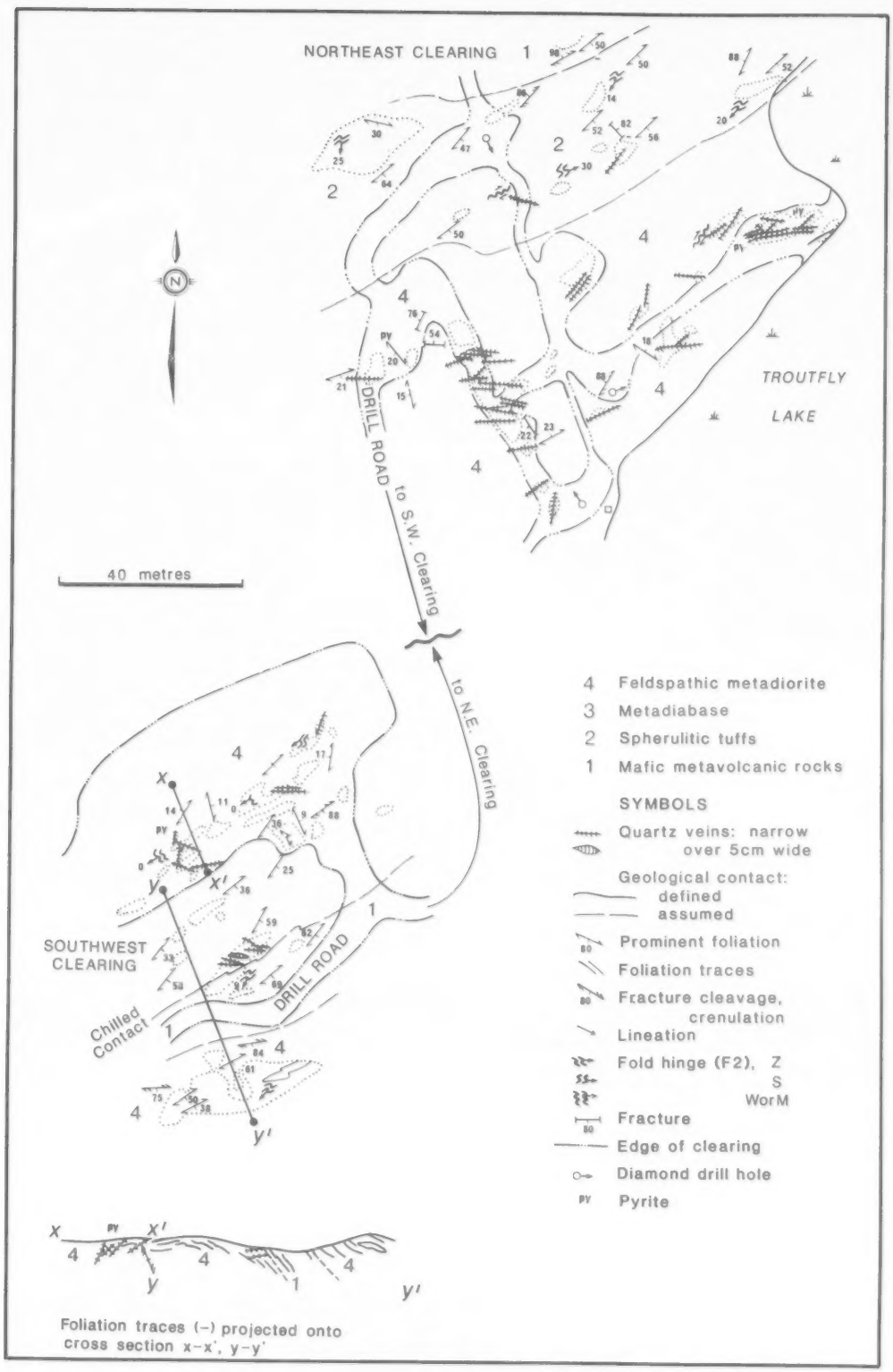

Figure 012.4. Geology of the north zone, Mistango (Troutfly) Lake area.

showing is sited in metadiorite that is traversed by northeast-trending, sinistral shear zones and a minor, easterly trending shear zone. Porphyroblasts of pyrite and pyrrhotite occur in the more schistose rocks, and porphyroblasts of magnetite, epidote, calcite, and tourmaline are particularly abundant within and around the main shear zone. The southern showing occurs next to the southern, schistose contact of the metadiorite. It consists of rusty weathering, highly silicified and carbonatized rock, containing abundant pyrite, tourmaline, green muscovite, and pink calcite. The altered rock occurs in a steeply dipping, metre-wide zone striking 340°, next to a northeasterly striking shear zone. A northeasterly striking foliation is discernable through the intense alteration, indicating replacement rather than simple veining. A crack in the core of the zone, filled with vuggy quartz and calcite, is probably the extension fracture which provided access for mineralizing fluids. Its orientation relative to the shear zones suggests that it is one of the normal extension fractures that are characteristically sandwiched between shear zones in wrench systems.

Metavolcanic rocks cut by irregular apophyses of the northern contact of the hornblende metadiorite intrusion underlie the area around the "Beartrack N" Occurrence. Several steeply dipping schistose zones strike at about 065° across the metavolcanic rocks. Subordinate, more northeasterly trending, schistose zones are sited in the metadiorite. The auriferous mineralization is exposed in three pits excavated north of the metadiorite, and consists of concentrations of pyrite in a multiple, north-striking, quartz vein in the western pit, and pyrite and arsenopyrite in a silicified, east-northeasterly trending, shear zone in the two eastern pits. The vein shows little marginal alteration, whereas abundant carbonate, tourmaline, patchy silicification and fine-grained pyrite extend at least 1 m north of the silicified shear zone. The vein fills another normal extension fracture, here related to the easterly shear zones.

In summary, known gold mineralization at Beartrack Lake occurs in shear zones and normal extension fractures at either end of the metadiorite stock. The structural embayment formed between the Cross Echo and Gardnar Lake Stocks was accommodated partly by activity on the numerous, conjugate shear zones and by normal extension between them. Thus, many more extension fractures and veins are predicted to occur here. However, these fractures, when formed within wrench settings, potentially terminate against shear zone walls, making the location of unexposed veins difficult to predict. Following the shear zones themselves, which are relatively planar, might be a worthwhile exploration tactic. Such an investigation, and the uncovering of other showings, might reveal whether open extension fractures or a competent body, such as the metadiorite, were necessary in addition to the shear zones for adequate hydrothermal focusing.

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013. Laval and Hartman Townships Area, District of Kenora

Ben Berger

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

Laval and Hartman Townships were mapped to improve the geological database, thereby assisting in the exploration for gold. Mapping successfully subdivided the supracrustal lithologies into lithostratigraphic groups, and, in the case of the Neepawa metavolcanic group, has resulted in further subdivision into two formations; one formation has indication that mafic calc-alkalic volcanism was active. Evidence indicates that an early period of thrusting deformed the supracrustal rocks prior to a second deformational event.

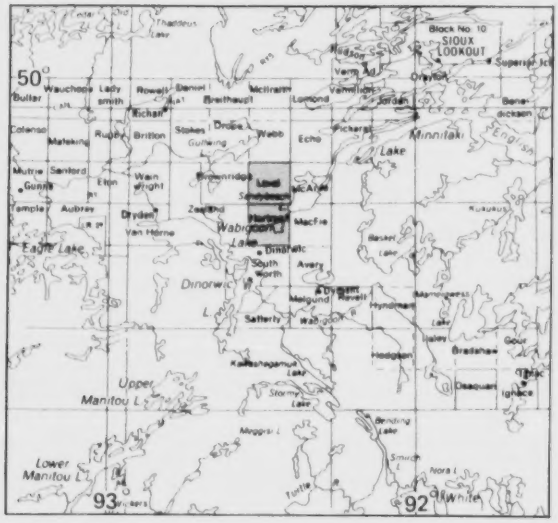
Gold is known to occur in three showings in the map area. Although many assays are still pending, two selected grab samples collected by the field party south of Beartrack Lake returned 0.92 ounce gold per ton and 0.248 ounce gold per ton.

The Laval and Hartman Townships area is bounded by 49°42′42″N and 49°53′13″N Latitudes and by 92°24′38″W and 92°32′39″W Longitudes (*see* location map). Laval and Hartman Townships (approximately 115 km^2) were mapped at a scale of 1:15 840. Access is easily obtained via Highway 72, and the nearest towns are Dryden (43 km west of the map area) and Sioux Lookout (55 km north of the map area). Seasonal gravel roads and bush trails provide access to most of the map area; however, aircraft were used to map the Rafter Lake area. Most of the larger lakes are accessible by road or by portage.

MINERAL EXPLORATION

Hurst (1933) reported mineral exploration was active in the entire Sioux Lookout area in the early 1900s; however, it was not until the discovery of gold mineralization in Echo Township in 1946 that exploration was focused in the map area (Page and Christie 1980). Between 1946 and 1952, three gold showings were discovered and explored by various companies. In the Beartrack Lake area, Graham Bousquet Gold Mines Limited discovered, trenched, and diamond drilled (total 366 m) two separate gold showings (Assessment File Research Office, Ontario Geological Survey (AFRO), Toronto). Showing 1, west of Beartrack Lake, consisted of pyrite, arsenopyrite, and chalcopyrite-bearing quartz veins which assayed up to 0.30 ounce gold per ton from grab samples. The host rock was described as a "shear zone" cutting mafic metavolcanics and diorite. Showing 2, south of Beartrack Lake, consisted of pyrite, sphalerite, galena, and magnetite hosted in sheared and altered diorite. Assays returned up to 0.75 ounce gold per ton and 5 to 7 percent zinc. Diamond drilling failed to establish subsurface continuity of ore-grade zones in either showing.

Amant Gold Mines Limited and Calder-Bousquet Gold Mines Limited reported auriferous quartz veins near the south end of Troutfly Lake in 1951 (AFRO, Toronto). Neither company carried out extensive exploration, although Calder Bousquet reported an assay of 0.12 ounce gold per ton from one of the veins.



LOCATION MAP

Scale : 1:1 584 000 or
1 inch to 25 miles

Mistango Consolidated Resources Limited has recently restaked this area and is currently carrying out a major exploration program including diamond drilling. A gold assay of 0.49 ounce gold per ton over 5.8 feet (1.75 m) was reported from one diamond-drill hole (The Northern Miner, February 2, 1987, p.10).

Exploration for base metals began in the 1960s (Page and Christie 1980) and has been sporadic since that time. A number of companies have flown airborne electromagnetic and magnetic surveys and have tested selected geophysical anomalies by diamond drilling. Hollinger Mines Limited carried out exploration in southwestern Laval Township in 1978 searching for lead-zinc mineralization. Five diamond-drill holes (total 598 m) encountered subeconomic mineralization with maximum values of 0.98% Pb, 0.78% Zn, 0.15% Cu, and 2.49 ounces Ag per ton over narrow widths. Canadian Nickel Company Limited and Selco Mining Corporation Limited have also carried out diamond drilling totaling about 948 m in the map area without making significant discoveries.

A number of mining claims, mostly in Laval Township, are currently in good standing and exploration by Mistango Consolidated Resources Limited, centred on the gold showing at the southern end of Troutfly Lake, is in progress.

GENERAL GEOLOGY

The map area is underlain by Precambrian (Archean) supracrustal rocks composed of mafic and felsic metavolcanics, metasediments, and related intrusive rocks which have been intruded by Archean granitoid stocks (Figure 013.1). Laval and Hartman Townships were previously mapped by Satterly (1943) who subdivided the supracrustal rocks into groups of predominantly metavolcanic or metasedimentary assemblages. Turner and Walker (1973) subdivided the supracrustals into groups in the Sioux Lookout area and subsequent workers (Page and Christie 1980; Trowell *et al.* 1980, 1983; Berger *et al.* 1987a, 1987b, 1987c) have adopted these group names and extended their boundaries southwest of Sioux Lookout to the map area. Groups recognized by Turner and Walker (1973) in the map area include the Southern Volcanic Belt, the Minnitaki Group, the Central Volcanic Belt also known as the Neepawa Group (Trowell *et al.* 1983), and the Abram Group. The Thunder River Volcanics (Satterly 1943) do not easily fit into these groups; however, they may be related to the Southern Volcanic Belt.

The Southern Volcanic Belt (Wabigoon Volcanics, Satterly 1943), which is restricted to the southern and western parts of Hartman Township, is composed predominantly of mafic metavolcanic flows with minor mafic pyroclastics and rare clastic metasediments. Pillow structures and plagioclase phyric flows ("leopard rock") are the major primary features preserved in these rocks and occasionally pillow breccias and bedding planes in tuffs are present. Geochemical analyses of representative samples from the Melgund Lake area (Berger, in preparation) show that these rocks are predominantly high iron tholeiites.

The Minnitaki Group underlies central Hartman Township and southern Laval Township, and is equivalent to the Zealand Sediments and the Thunder Lake Sediments mapped by Satterly (1943). The Minnitaki Group is composed predominantly of clastic wacke and siltstone and exhibits graded beds interpreted as being deposited by turbidity currents. Minor sulphide and oxide facies ironstones are interbedded with the wacke but do not form large mappable units. Pebbly wacke beds occur in a few places and are the coarsest metasediments present. Felsic metavolcanic tuff, crystal tuff, and lapilli-tuff are interbedded with the wacke and form large mappable units in the Laval Lake area. Mafic tuff is also interbedded with the wacke but does not form mappable units and is uncommon. The contact between the Minnitaki Group and the Southern Volcanic Belt is obscured by the Hartman Lake Stock and the stratigraphic facing directions are unreliable in this area. The contact between the Minnitaki Group and the Neepawa Group appears to be conformable, and intercalations of metasediments with metavolcanics are common. Reversals in stratigraphic facing directions are common due to folding and faulting, but, based on mapping by Berger *et al.* (1987a, 1987b, 1987c), the Minnitaki Group appears to overlie the Neepawa Group.

The Central Volcanic Belt or Neepawa Group (Brownridge Volcanics, Satterly 1943) is composed of metavolcanics which are divisible into two formations (Figure 013.1). Formation A forms a broad band that extends southwest from northeastern Laval Township to the Rafter Lake area. Formation B underlies the Beartrack-Troutfly Lakes area and the islands and eastern shore of Rafter Lake. The contact between the two formations is transitional and based on field relationships. Formation A is older than Formation B.

Formation A is composed predominantly of amphibolitic mafic flows and related subvolcanic intrusions. These rocks are dark green to black on the weathered surface, and are composed of massive to pillowed flows with interlayered heterolithic mafic pyroclastics. Felsic metavolcanic flows and pyroclastics locally form mappable units but are subordinate members of Formation A. Variolites form a distinctive sequence in Formation A. Varioles in massive mafic flows were commonly observed to gradually increase in abundance from approximately 30 percent, toward the upper stratigraphic contact where, in many places, they coalesced into massive, glassy-looking dacitic to rhyolitic rocks. In some places these flows are overlain by felsic tuffs containing "varioles" and fragments of coalesced felsic lava. This sequence of rocks provides a readily identifiable marker horizon extending from the eastern boundary of Laval Township to west of Gardnar Lake. The origin of these textures is unknown at present.

Subvolcanic gabbro/diorite sills and dikes intrude the metavolcanics of Formation A, and in several instances, textures and field relationships indicate that these bodies breached the surface, producing flow equivalents. These rocks commonly contain plagioclase and/or hornblende phenocrysts which appear to form cumulate phases within the intrusions.

Formation B of the Neepawa Group is composed of mafic to intermediate metavolcanic pyroclastics with subordinate intermediate to felsic flows. These

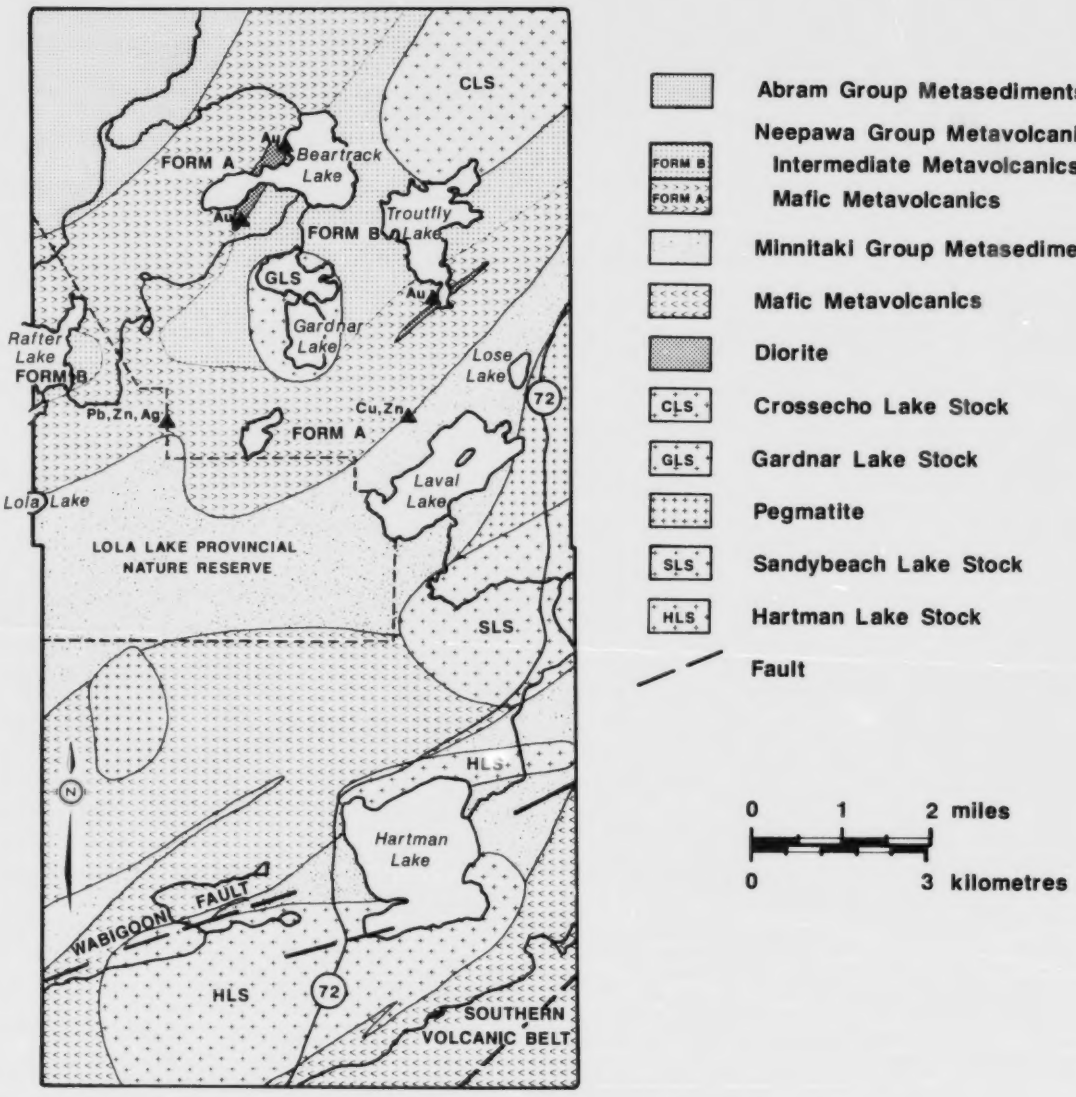


Figure 013.1. *General geology of Laval and Hartman Townships Area, District of Kenora.*

rocks are characterized by grey-green weathering surfaces and contain either prominent euhedral hornblende or plagioclase phenocrysts and are interpreted to represent products of explosive calc-alkalic volcanism. Distinctive textures in these rocks include square hornblende phenocrysts interpreted to be primary and/or pseudomorphic after clinopyroxene and trachytic textured pyroclasts and flows. The pyroclastic deposits in the Beartrack Lake area are unsorted, ungraded, poorly stratified, heterolithic tuff breccias that become better organized in the Rafter Lake area. Flows are subordinate and are composed of mafic to felsic massive and pillowed members.

At Beartrack Lake, an irregularly shaped composite diorite stock has intruded both formations of the Neepawa Group, and fragments from the stock are incorporated in Formation B pyroclastic deposits and trachytic flows are in gradational contact with the intrusion. This indicates that the stock was subvolcanic and was a local source for some of the metavolcanics of Formation B.

The Abram Group or Brownridge Sediments (Satterly 1943) underlie the northwestern corner of Laval Township. These rocks are composed of arenaceous wacke interbedded with siltstone and felsic metavolcanic crystal tuff and tuff-breccia. The clastic metasediments are northwest facing, thinly to thickly bedded, containing well-preserved graded beds, cross-stratification, scour marks, and "rip-up" clasts that are indicative of deposition by turbidity currents. Turner and Walker (1973) have subdivided the Abram Group into formations and, based on their descriptions, the metasediments in the map area appear to be most closely related to the Daredevil Formation

which contains both felsic metavolcanics and turbiditic wackes. There is also a close similarity in lithologies and depositional environments between the Abram Group and the Minnitaki Group in the map area.

The Thunder River Volcanics (Satterly 1943) form a band of mafic metavolcanic flows and amphibolites that extends from Hartman Lake to the western boundary of Hartman Township. These rocks are composed of massive and pillowed amphibolitic mafic flows, some of which contain plagioclase varioles. These rocks are intercalated with clastic metasediments of the Minnitaki Group and do not readily fit into previously described groups. However, these rocks appear to be contiguous with members of the Southern Volcanic Belt and are tentatively correlated with this group.

A number of granitoid stocks intrude the supracrustal rocks, including the Hartman Lake Stock, the Sandybeach Lake Stock, the Gardnar Lake Stock, the Crossecho Lake Stock, a distinctive suite of granitic pegmatites, and a number of feldspar and quartz feldspar porphyritic dikes.

The Hartman Lake Stock is a composite granitoid intrusion composed mainly of a pink weathering granodiorite phase, a pink to red granite aplite phase, and a white weathering quartz feldspar porphyritic border phase which, in part, is physically separated from the main stock. The granodiorite underlies most of the stock in the west-central part of Hartman Township. It is a medium- to coarse-grained, quartz-rich rock which is locally deformed to mylonite where it is cut by the Wabigoon Fault. The pink granite aplite occurs as a massive intrusive phase east of Hartman Lake and as stringers and dikes cutting both the granodiorite and Southern Volcanic Belt rocks. The quartz-feldspar porphyry occurs along the southeastern and eastern margins of the stock and intrudes the earlier phases of the stock. Along the northeastern margin of the stock, the porphyry occurs as apophyses, dikes, and irregular bodies intruding Minnitaki Group metasediments and Thunder River Metavolcanics. A distinctive intrusion breccia occurs along Highway 72 where the porphyry has partially assimilated mafic amphibolite.

Only the western third of the Sandybeach Lake Stock occurs in the map area and it is located along, and west of Highway 72 in northeastern Hartman Township. The stock is a grey weathering, foliated, mafic xenolith-bearing quartz monzonite to quartz-diorite. The rock is medium grained, homogeneous, and contains hornblende and biotite. A syenogabbro phase composed of large pink feldspars in a biotite-hornblende groundmass occurs along the western margin south of Laval Lake.

The Gardnar Lake Stock is centred under Gardnar Lake and is an equigranular to slightly feldspar porphyritic, biotite-bearing granodiorite. For the most part, the stock is homogeneous with narrow (1 to 30 cm) pink and white aplite dikes cutting the stock and host rocks near the borders. Quartz-tourmaline veins are found along the western margin. A number of granitic dikes intrude the metavolcanics southwest of the stock; however, their relationship to the stock is uncertain at this time.

The Crossecho Lake Stock is an oval intrusion underlying the northeastern part of Laval Township. It is predominantly a pink, quartz porphyritic granodiorite with minor white tonalite and numerous pink granitic aplite dikes and stringers. Biotite usually makes up less than 10 percent of the rock, and in many places comprises less than 5 percent of the rock. Large quartz phenocrysts (up to 2 cm in diameter) are commonly doubly terminated and this distinguishes this stock from the other granodiorites in the map area. Quartz tourmaline veins are also common in this stock.

A distinctive suite of white and pink weathering granitic pegmatites and aplites occurs along Highway 72 in southeastern Laval Township, on the shores of Laval Lake, and in the northwestern part of Hartman Township. The white variety is composed of quartz, sodic and potassic feldspar, muscovite, and biotite. Garnet, tourmaline, and rarely fibrolitic sillimanite occur as accessory minerals. The pink pegmatite is mineralogically similar to the white variety but contains less tourmaline and no sillimanite. White and pink pegmatite occur together in the field and the only noticeable difference is that white pegmatite contains mostly metasedimentary xenoliths, whereas the pink variety contains mostly amphibolitic xenoliths. These rocks crosscut the Sandybeach Lake Stock and are among the youngest rocks in the map area.

Throughout the map area, feldspar and quartz-feldspar porphyry dikes intrude the supracrustal rocks. Based on spatial proximity, many of these dikes are thought to be related to the felsic metavolcanics in the Neepawa Group. Some of these dikes may also be related to the granitic stocks such as the Hartman Lake Stock or the Crossecho Lake Stock. However, many dikes are of uncertain origin. In particular, a number of monzodioritic to feldspar phyric dikes intruding metavolcanics southwest of Gardnar Lake are compositionally different from the Gardnar Lake granodiorite stock and appear to form a separate intrusive centre.

STRUCTURE AND METAMORPHISM

Two periods of deformation have affected all of the supracrustal rocks in the map area, and around the peripheries of some of the granitoid stocks a third period of deformation is locally preserved. Evidence of the first deformation is preserved in the stress shadows of the Crossecho Lake and Gardnar Lake Plutons. Here, subhorizontal foliations, lineations, shearing, and bedding indicate thrusting was possibly responsible for the first phase of deformation (Chorlton, Article 012, this volume).

The second deformation is well preserved and has affected all of the rocks in the map area. It is characterized by north- to northeast-trending foliations and northeast- or southwest-trending lineations and fold axes. The second deformation has tightly buckled the metavolcanics about subvertical fold axes, and, in the area southwest of the Crossecho Lake Stock, low amplitude folds imposed upon the subhorizontal strata of the first deformation has caused multiple repetition of metavolcanic units. The second deformation has resulted in transposition of units

in many places and has created very complex geology.

Intrusion of some of the granitoid plutons has imposed foliations and mineral lineations upon the supracrustal rocks. These structures are localized to the peripheries of the plutons and represent the third period of deformation in the map area.

The Wabigoon Fault as described by Satterly (1943) and Blackburn *et al.* (1985) is characterized by intensely sheared rocks marking the boundary between north-facing mafic metavolcanics south of the fault and south-facing clastic metasediments north of the fault. In the map area, the Hartman Lake Stock intrudes along this interface and the Wabigoon Fault has cut the Hartman Lake Stock as a series of separate but subparallel shear zones. Each zone is marked by the development of mylonitic textures and each shows a pronounced dextral asymmetry defined by rotated foliation at the boundaries. Purple fluorite commonly occurs along the foliation planes and is interpreted by the author as evidence that the structures are deep seated.

A second major northeast-trending structure cuts the Southern Volcanic Belt southeast of the Hartman Lake Stock. This structure is interpreted to represent the extension of the Manitou Straits Fault (Blackburn 1982) into the map area. It consists of intensely sheared mafic metavolcanics which locally contains sulphide mineralization and brown carbonate alteration. Its relationship to the Wabigoon Fault is as yet unclear; however, northeast-trending microfaults within the Hartman Lake Stock clearly cut and sinistrally offset west-trending foliations interpreted to belong to the Wabigoon Fault system.

Most of the area has been metamorphosed to amphibolite facies. Indicator minerals in the metasediments include staurolite, garnet, and andalusite. Metamorphic mineral indicators in the mafic metavolcanics include the widespread development of garnet and hornblende and the local development of pyroxene in metatexitic rocks. Partial melting of the metasediments is indicated by the development of the white garnet-sillimanite bearing pegmatites which occur extensively along the eastern boundary of Laval Township and in the northwestern part of Hartman Township.

Areas of greenschist facies metamorphism occur south of the Hartman Lake Stock and in the Beartrack Lake-Troutfly Lake area. Chlorite, epidote, and actinolite are most common in these areas.

ALTERATION

All rocks, including the granitoid stocks and pegmatite intrusions north of the Wabigoon Fault, have undergone some degree of tourmalinization. Tourmaline occurs mainly in two environments. Firstly, tourmaline occurs in quartz veins that intrude along the northeast D_2 foliation planes and along extension fractures oriented northwest, north-northeast, and east-northeast. This type of tourmalinization is most common and occurs in all rock types. Several assays from these quartz-tourmaline veins returned *nil* gold and silver.

In the second environment, tourmaline occurs within the host rock as individual crystals, rosettes, or as massive replacement of such primary features as pillow selvedges, vesicles, and original porous pyroclasts. This type of tourmalinization occurs mainly in the Neepawa Group metavolcanics in the Beartrack-Gardnar-Troutfly Lakes area. Occasionally, andalusite and scheelite are present and, although all three gold showings in the map area are spatially related to this type of tourmalinization, quartz-tourmaline veins are also present in the vicinity of each showing.

Locally, hydrothermal silicification and carbonatization have affected the supracrustal rocks. This type of alteration is manifested along the extension of the Manitou Straits Fault and in the area southwest of Troutfly Lake. In particular, pervasively silicified and carbonatized gabbroic sills at the southern end of Troutfly Lake are the current focus of gold exploration by Mistango Consolidated Resources Limited.

ECONOMIC GEOLOGY

There is very good economic potential for gold mineralization and, to a lesser extent, for base-metal mineralization in the map area. Gold is known to occur in three separate showings in the map area. Mistango Consolidated Resources Limited is currently exploring a gold showing at the southern end of Troutfly Lake. Gold occurs with galena and pyrite in east-northeast-trending quartz veins hosted by a silicified and carbonatized portion of a gabbro/diorite sill intruding the Neepawa Group metavolcanics. The altered rock is white to pink weathering and has been referred to as "granodiorite" by previous workers; however, field relationships and mineralogy clearly indicate that the altered rock was originally a gabbro. Gold tenor is erratic within the altered zone and Mistango reported gold values up to 0.49 ounce per ton over 5.8 feet (1.75 m) from previous diamond drilling (The Northern Miner, February 2, 1987, p.10).

Two gold showings previously worked in 1951 by Graham Bousquet Gold Mines Limited occur in the Beartrack Lake area. The northern showing (Showing 1) is hosted in an east-northeasterly shear zone conjugate to the principal D_2 foliation and contains pyritic quartz veins hosted in tourmaline-bearing and pyritic mafic metavolcanics. Gold assays up to 0.3 ounce per ton were previously reported, and resampling of the quartz veins and host rock by the author returned up to 340 ppb gold and 750 ppm arsenic. Mapping 200 to 300 m west of the showing located extensive areas of silicified and tourmalinized diorite and quartz diorite containing pyrite and scheelite. Assays are pending; however, this area is considered by the author to be a very favourable exploration target.

The southern showing (Showing 2) contains pyrite, sphalerite, magnetite, and arsenopyrite in a north-northeasterly trending sericitic shear zone which is also conjugate to the principal D_2 foliation. The shear zone is hosted within a diorite intrusion and Graham Bousquet Gold Mines Limited reported analyses of up to 0.75 ounce gold per ton and up to 7 percent zinc. Resampling by the author returned assays of 0.248 ounce gold per ton, 0.92 ounce gold

per ton, and 300 ppb gold from three separate grab samples. Zinc values up to 2860 ppm, arsenic values up to 1000 ppm, and silver values up to 6 ppm (0.17 ounce per ton) were also returned. Clearly this whole area warrants further exploration.

At all three gold showings, there appears to be a structural control related to the second period of deformation, and gold is localized in deformed mafic rocks with mineralization concentrated in zones which are conjugate to the main northeast foliation.

Base-metal potential is greatest within the Neepawa Group. Most previous exploration has concentrated in the area from Lola Lake in the west to Laval Lake in the eastern part of the map area. Within this area, there are several reports of minor lead, zinc, and copper mineralization. The most important discovery to date is Hollinger Mines Limited's lead-zinc-silver showing located west of Diamond Lake in the Lola Lake Provincial Park Nature Reserve. During the field season, several sulphide showings within this area were sampled, with the most significant results to date being 1180 ppm copper, 6720 ppm zinc, and 50 ppb gold. These results were obtained from sulphide pods that occur within interpillow material along the Diamond Lake road west of Laval Lake.

The white weathering granitic pegmatites are potential hosts of lithium and rare earth element mineralization as well as potential hosts of industrial minerals. Previous work by Redden (in preparation) has shown that muscovite separates from these rocks contain elevated lithium (1450 ppm) and gallium (200 ppm) values, indicating that they are highly evolved and analogous to the lithium-bearing pegmatites closer to Dryden.

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014. Structural Studies in the Beardmore–Geraldton Belt and in the Quetico and Wawa Subprovinces

Howard R. Williams

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

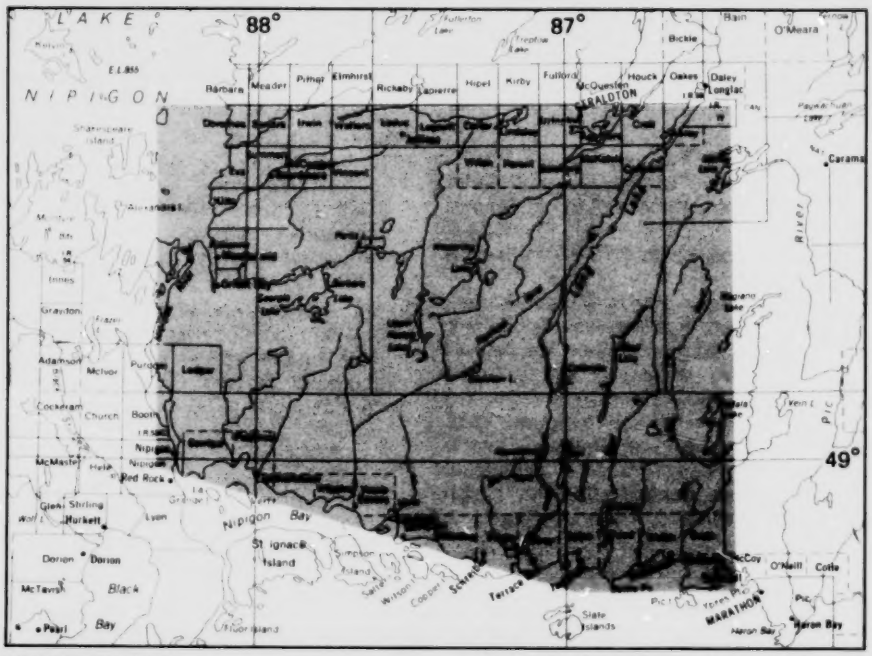
The intent of this project is to produce a model for Archean tectonic development and to investigate the structural controls for precious metal mineralization in the Beardmore-Geraldton Belt. These two topics are clearly related, both in time and space. A combination of reconnaissance and detailed structural field work within the region bounded by Lake Superior, Lake Nipigon, and Long Lake, and stretching 20 km north of Highway 11 (Location Map), has allowed erection of major tectonic divisions, based on changes in deformation and lithostratigraphic style (Williams 1986). The work this year has concentrated on enlarging the database by increasing the density of observations in unmapped or little known areas.

Interpretation of observations made previously in the program suggested (Williams 1986) that the Beardmore-Geraldton Belt is the northern part of an imbricate thrust stack which, together with the metasedimentary pile of the Quetico Subprovince, was developed as a fore-arc accretionary prism along the southern margin of the Wabigoon granite greenstone terrane. Detailed measurement of structures along lithological boundaries in the Beardmore-Geraldton Belt in 1987 has confirmed, with only minor modification, this tectonic hypothesis.

Unless otherwise stated, all references to sediments and sedimentary rocks are understood to be metasediments and metasedimentary rocks.

This report presents preliminary conclusions from observations made in the 1987 field season. These observations and conclusions include:

1. Along the Wabigoon-Quetico Subprovince boundary, at the southern margin of the Beardmore-Geraldton belt, further evidence of a strong down-dip stretching prior to superimposed dextral shear has been collected, and the style of deformation within the belt as a whole has been investigated for its homogeneity.
2. Locally southward-younging sections of steeply dipping sedimentary rock within the southern and central metasedimentary portions of the Beardmore-Geraldton Belt (Mackasey 1975, 1976; Carter 1987) were investigated to determine their extent and significance.
3. Within the Quetico metasedimentary package in the Lake Jean area (Pye 1965), an area of ultramafic and mafic sediments has been recognized.



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

4. Investigation of the deformation style within the Quetico metasedimentary rocks has revealed more small-scale folding than had hitherto been recognized, with steeply plunging axes in the low metamorphic grade areas and shallow plunging axes in the central, high metamorphic grade area.
5. A number of small ultramafic bodies have been discovered within the Quetico metasedimentary terrane.
6. Close to or at the Wawa-Quetico Subprovince boundary, north and northeast of Terrace Bay, the eastern continuation of the Big Duck Lake Greenstone Belt (Pye 1963) and its deformation state were investigated.
7. The evidence for folding and shear deformation within the Jackfish-Middleton Greenstone Belt east of Terrace Bay (Walker 1966, 1967) was reviewed.

SUMMARY OF FIELD WORK

Whilst almost all lithological contacts within the Beardmore-Geraldton Belt are zones of deformation, the northern contacts of individual sedimentary packages, often associated with thin units of iron formation (e.g. Partridge Lake, Clist Lake), yield evidence of increased deformation intensity relative to the complementary southern contacts (e.g. Bush Lake and the eastern shore of Lake Nipigon). The intensity may be qualitatively assessed by recognition of highly fissile rocks whose formation involves the deformation and ultimate destruction of primary textures. Useful also are the development of linear structures, such as stretched pillows and mineral aggregates, and the growth of elongate minerals such as amphibole. The development of crenulation fabrics and kink bands is thought to be an advanced stage in the evolution of structures in these shear zones (Williams 1986). The work this summer clearly shows that early, down-dip stretching and tectonic transport, involving south-side-down sense of motion on now nearly vertical foliation surfaces, were followed by a dextral sense of displacement on these same shear surfaces, which parallel the lithostratigraphic units. In many cases, the subsequent movement all but obliterated the evidence for the earlier. It is significant that most of the gold occurrences in the region coincide with, or are close to, these highly deformed lithologies.

Within several hundred metres of the northern contact of sediments with mafic volcanics in the southern and central metasedimentary belts of the Beardmore-Geraldton Belt, the sediments are locally southward-younging, in contrast with the general northward-younging trend for the belt as a whole. This local reversal is probably the result of folding, but small-scale fold structures are insufficient in number to suggest the presence of larger ones. The reversal is consistent over several tens of kilometres along the two contacts and superimposed upon it is the increased deformation state described in the preceding paragraph. Locally, the deformation is sufficiently intense to annihilate the evidence used to determine younging, but this is usually restricted to the zone closest to the lithological contact. The younging reversal has been interpreted in terms of a megascopic fold associated with the tectonic transport alluded to in Williams (1986).

During collection of structural data from the area of the Quetico metasediments mapped by Pye (1965) around Lake Jean, a zone several hundred metres long, and perhaps a hundred metres wide, of ultramafic sediments was recognized. This is surrounded by an elongate zone of mafic sediments at least several kilometres in extent, forming the core of a megascopic fold structure. Preliminary examination of these centimetre- to metre-scale, bedded, dark-coloured, non-magnetic sediments indicates that they are of local extent, have a chloritic, talcose, and carbonate-rich nature, and iron-poor composition. A zone of similar mafic and ultramafic sediments, of unknown dimensions, was also found along the Namewaminikan River within the southern metasedimentary belt of the Beardmore-Geraldton Belt. The restricted distribution of these rocks within monotonous wacke turbidites is of extreme tectonic significance, since rocks of this unusual composition are usually associated with the development of melange or imbricate packages of sediment within accretionary prisms (Lockwood 1971).

Within the metasedimentary rocks of the Quetico Subprovince, shallow-plunging folds have been recognized in association with more strongly deformed and metamorphosed rocks of the central and southern zones. The scale of folding is of the order of several hundred metres in wavelength or less, and is best seen on the shore of Lake Helen, north of the Town of Nipigon. These folds, which have shallow axes and steeply oriented axial surfaces, are relatively late in the tectonic evolution of the area for they deform an already strongly foliated sequence of metasedimentary migmatites and associated granitic sheets. In the lower metamorphic grade sedimentary sequence to the north of those just described, folding is inhomogeneously distributed, but is concentrated in zones of high deformation in which metre to tens-of-metre scale folds are suggested from younging reversals. Actual folds of this scale are hard to recognize because of the lack of a distinctive mappable stratigraphy. Axes of these folds are steeply but variably plunging, and the folds may be similar to the deformation style described for the Beardmore-Geraldton Belt by Kehlenbeck (1986), forming under conditions of localised high strain and perhaps representing zones separating accreted sedimentary packages (Williams 1986).

Metre-scale ultramafic bodies of hornblende-, talc- or chlorite-rich lithologies occur sporadically throughout the Quetico metasedimentary rocks. Most examples are less than a metre across, parallel the stratigraphic layering, are mantled by metasomatic reaction zones rich in micas, and are internally homogeneous. None is demonstrably sedimentary or intrusive in origin; most, if not all, are foliated and metamorphosed and are, therefore, considered to have been emplaced into the stratigraphy at an early stage, perhaps tectonically. They are not spatially associated with gabbro or other mafic rocks, and their enclosing host sediment is not significantly different from that which does not contain ultramafic bodies. The bodies are not noticeably magnetic, and

are probably too small to be found except by the most detailed geophysical methods.

North of Terrace Bay, Carter (1982a, 1982b) mapped a series of schistose and gneissic rocks along strike from the Big Duck Lake Greenstone Belt (Pye 1963). These rocks were recognized as highly deformed greenstone assemblages by Williams (1986), and were thought to represent a several kilometre wide zone of very high deformation intensity near the contact of the northern edge of the Wawa Subprovince with the Quetico Subprovince. Kinematic indicators, such as stretching and mineral lineations, crenulation fabric development and folds, suggest that, as described previously for the Beardmore-Geraldton Belt, the dominant sense of motion on this shear is down-dip and south-side-down. In contrast to the shear zones at the northern boundary of the Quetico Subprovince, this shear zone was active at amphibolite facies metamorphic conditions producing gneisses from all lithologies, especially gabbros, anorthositic rocks, and highly altered pillow lava sequences. The significance of these mylonitic rocks, at or near the subprovince boundary, depends upon the location of that boundary. Carter (1982a, 1982b) placed it at the northern margin of the mafic succession, in accordance with the defined boundary elsewhere, but the recognition this year of 1 m thick conglomerate bands within the Quetico sediments north of this boundary suggests that at least some of the sediments defined as part of the Quetico Subprovince might have more in common with the Big Duck Lake Greenstone Belt, which is part of the Wawa Subprovince. Reconnaissance traverses indicate that gabbros, and ultramafic and anorthositic rocks occur as enclaves within granitic and migmatitic metasedimentary rocks at or near the northern margin of the Wawa Subprovince. The tectonic significance of these rocks is still unclear.

Within the Wawa Subprovince, the Jackfish-Middleton Greenstone Belt mapped by Walker (1966, 1967) was examined, looking specifically at structural style. As in many greenstone belts, the intensity of deformation was found to be inhomogeneous; undeformed pillow basalt sequences are intercalated with extremely deformed, almost mylonitic, equivalents. In most cases, these shear zones parallel the stratigraphy, but they may have many orientations, including horizontal, as at Owl Lake. The interpretation of shallow-plunging fold structures from the use of stratigraphic younging directions in the Jackfish-Middleton area is difficult to reconcile with the measured fold axes, which are almost without exception steeply plunging. In addition, zones of intense layer transposition within the sedimentary sequences indicate that a simple structure, based on upright, shallow-plunging folds, is unlikely. It is possible that a combined fold-thrust model of deformation is more appropriate for the area.

The preceding paragraphs indicate the scope of study being carried out in an area of highly variable geology. Within the Superior Province, the broad tectonic and lithostratigraphic subdivision into greenstone belts and metasedimentary gneiss terranes may be simplistic and detrimental to an understanding of how these rocks developed. Only when their respective tectonic developments can be compared will their contrasting stratigraphies and mineralization styles be put in the correct context so that predictions about the geology can be made with any confidence.

ACKNOWLEDGMENTS

The untiring support and inquiry of Thomas Huml are greatly appreciated.

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015. Northern Long Lake Area, District of Thunder Bay

D.U. Kresz and Borys Zayachivsky

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

The Northern Long Lake area is transected by two major east-trending deformation zones which were investigated during the present survey. These deformation zones are eastward extensions of gold-bearing structures of the Geraldton Gold Camp.

Field work carried out during the Summer of 1987 consisted of mapping Houck, Oakes, Croll, and Abrey Townships, the northern half of Coltham Township, and an area directly east of Coltham Township, the eastern part of McQuesten Township, Longlac Indian Reserve 58, and the western portion of Longlac Indian Reserve 77. The 520 km^2 surveyed area is bounded by Latitudes 49°37′30″N and 49°50′25″N and Longitudes 86°32′50″E and 86°48′50″E.

Access to the map area is provided by Trans-Canada Highway 11, the Canadian National Railway, and the Trans-Canada gas pipeline right-of-way. Southern parts of the map area are accessible by gravel roads and by watercraft from Long Lake.

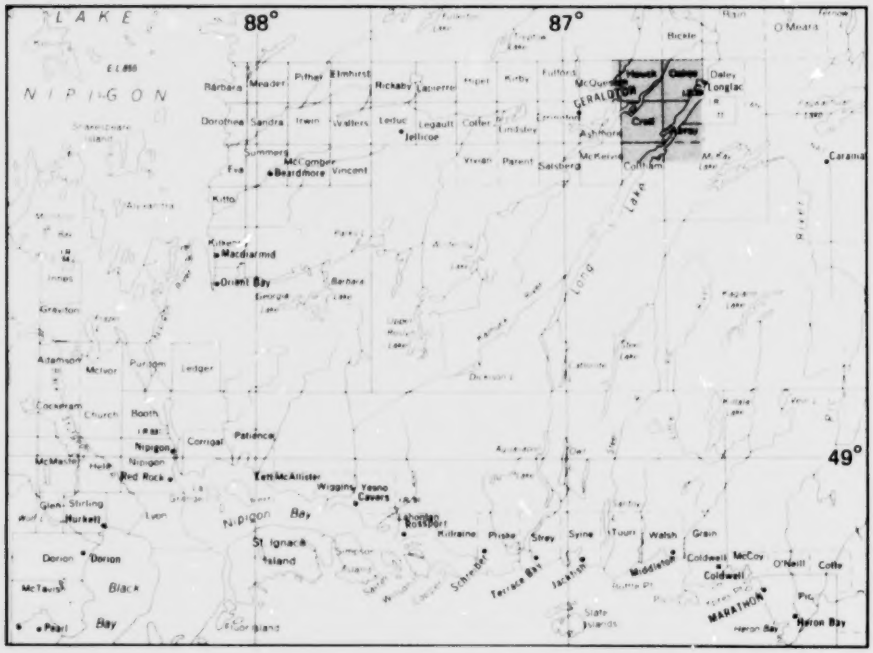
MINERAL EXPLORATION

Gold was first discovered in the Geraldton area in 1931. Extensive prospecting in the 1930s resulted in the discovery of many gold mines and occurrences (Horwood and Pye 1955).

As a result of recent renewed interest in gold in the Beardmore-Geraldton-Longlac region, exploration companies and prospectors are active in the Northern Long Lake area. Several abandoned gold mines and most known gold occurrences are presently being re-evaluated.

Ferau Resources Incorporated has concentrated exploration activity on the eastern side of Long Lake in the vicinity of the old MacFarlane and Coniagas Gold Occurrences (Fairbairn 1938) south of Abrey Township. In 1987, a program of diamond drilling, power stripping, and geological mapping was in progress. Ferau Resources Incorporated also holds ground covering the West Side Long Lake and the Long Lac Adair and Smith-Elliot Cold Occurrences described by Fairbairn (1938).

Geraldton Longlac Gold Incorporated is active in Coltham and Croll Townships. Recent activity has been concentrated on the old Burroughs Syndicate gold occurrences in Coltham Township described by



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

Mason and White (1986). In 1987, a program of diamond drilling and power stripping was in progress.

Discovery West Corporation holds claims in and south of Abrey Township. In April 1987, a ground magnetic and electromagnetic survey was conducted over the western part of the claim group. In late Summer 1987, linecutting, prospecting, and geological mapping was in progress.

Coulson Exploration Incorporated holds two claim groups in the map area: a block in southeastern Houck Township, centred on the Dam Gold Occurrence described by Mason and White (1986), and a block in western Croll Township. An airborne magnetic and electromagnetic survey was flown over the property in May 1987. Further exploration work during the summer included linecutting, prospecting, and geological mapping.

Duration Mines Limited holds a group of claims in Abrey Township which is part of a larger claim block extending east of Abrey Township encompassing the abandoned Theresa Gold Mine (Mason and White 1986). Dewatering of the Theresa mine shaft was in progress over the summer.

A gold occurrence discovered recently by William and Rachel Brinklow is located at the east-central boundary of Oakes Township. It contains narrow quartz veins with visible gold.

GENERAL GEOLOGY

The area (Figure 015.1) has been previously mapped by Fairbairn (1938). Macdonald (1942, 1943) mapped Houck and part of Coltham Township. The map area is also included on the Tashota-Geraldton geological compilation map (Pye *et al.* 1966), the revised compilation map for the Geraldton area (Stott 1984), and aeromagnetic Maps 2150G "Geraldton" (ODM-GSC 1962a) and 2151G "Longlac" (ODM-GSC 1962b).

The map area is situated in the eastern Wabigoon Subprovince, covers the east-central part of the Archean Beardmore-Geraldton Metavolcanic-Metasedimentary Belt (Mackasey 1970), and straddles the Wabigoon-Quetico Subprovince boundary. The supracrustal rocks consist principally of mafic metavolcanics, metasediments, and intercalated felsic to intermediate pyroclastics. All the supracrustal rocks have been metamorphosed under greenschist to amphibolite facies conditions. For descriptive purposes, the supracrustal rocks in the map area have been subdivided informally into six units: the northern, central, and southern volcanic and the northern, central, and southern sedimentary units (Figure 015.1).

The southern volcanic unit, composed of pillowed basalt and gabbro, straddles the southern boundary of the map area and is continuous over a distance of at least 120 km from Lake Nipigon to McKay Lake. The southern volcanic unit is well defined by a strong magnetic signature on the western side of Long Lake (ODM-GSC 1962a).

The central volcanic unit is traceable for approximately 160 km from Lake Nipigon to Klotz Lake. The unit outcrops in Croll and Abrey Townships and is intruded by the Croll Lake Stock. South of the intrusion, the volcanic rocks consist of massive, amygdaloidal flows whereas to the north, they have been found to be pillowed and amygdaloidal.

The northern volcanic unit underlies Houck and Oakes Township north of Kenogamisis Lake and Longlac. It is composed largely of amygdaloidal pillowed basalts. Intermediate to felsic lapilli-tuff and tuff-breccia occur intercalated among the mafic volcanic rocks in eastern Oakes Township.

Three distinct sedimentary units underlying the map area may be traced for considerable distance along strike outside of the map area.

The southern sedimentary unit underlies the northern half of Coltham Township and the area to the east. It consists of quartzofeldspathic sandstone, wacke, siltstone, banded magnetite iron formation, and polymictic conglomerate that exhibit a large variety of volcanic and granitic clasts.

The central sedimentary unit is composed of quartzofeldspathic sandstone, wacke, and subordinate polymictic conglomerate and underlies north-central Croll Township, southeastern Houck Township, and part of southwestern Oakes Township.

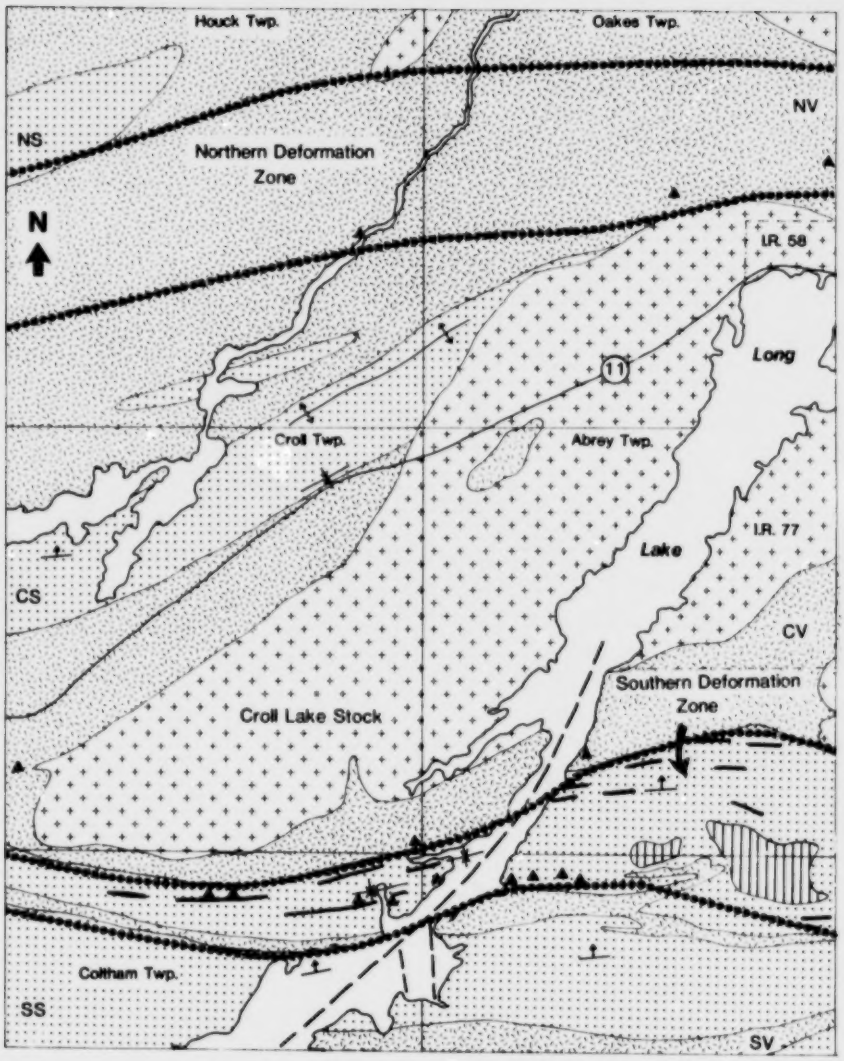
The northern sedimentary unit appears as a lens-shaped body within the northern volcanic unit of northwestern Houck Township, and is traceable for some 40 km (Stott 1984). The sedimentary rocks consist mainly of wacke with lesser magnetite iron formation.

The sediments of the northern unit are typical of turbidites displaying well graded sandstone and wacke beds. The presence of polymictic conglomerates, particularly within the southern sedimentary unit, suggests that the sediments were deposited in a submarine fan environment (Devaney and Williams, in preparation). Sedimentological similarities of the three units within the map area suggest that they may once have formed a single unit and were subsequently separated by the processes of tectonism and erosion (Devaney and Williams, in preparation).

Intrusive rocks comprise gabbro, feldspar, and quartz porphyry and granitic rocks. The gabbros are synvolcanic and occur within mafic volcanic rocks as dikes and sills. Syn- to posttectonic feldspar and quartz porphyry dikes occur within mafic volcanic and sedimentary rocks. Two elliptical bodies of quartz-feldspar porphyry occur within amphibolite grade sedimentary rocks along the southern boundary of Abrey Township (Figure 015.1).

Syn- to posttectonic intrusions are the Croll Lake Stock and a small tonalitic to granodioritic body in eastern Abrey Township. The Croll Lake Stock is a 25 km long and 10 km wide body exposed in Oakes, Abrey, and Croll Townships. It is composed of mafic inclusion-bearing massive to foliated tonalite to granodiorite with microcline porphyritic phases in its northern part.

Coarse-grained, mafic to ultramafic intrusive bodies, less than 50 m thick, displaying distinct textural and compositional layering, have been found within bedded arenites in the Southern Deformation Zone west of Long Lake. The similarity of textures, compositions, and internal layering associated with these rocks suggest that they may be part of a larger mafic-ultramafic body. The restriction of the bodies to



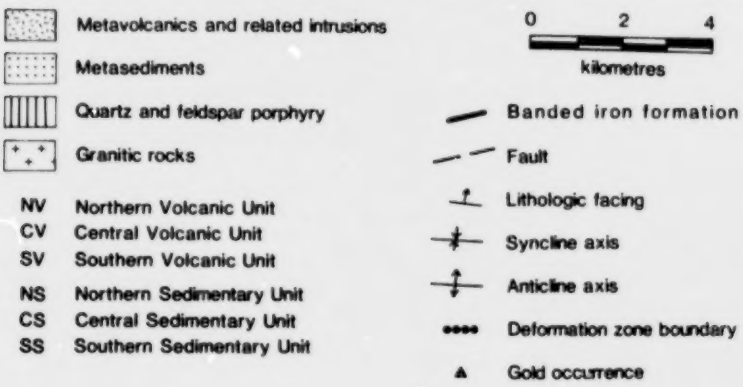


Figure 015.1. *Geological map of the Northern Long Lake Area.*

the deformation zone suggests they may be tectonically emplaced.

Two generations of Proterozoic north-trending diabase dikes crosscut all Archean lithologies. The earlier diabase is plagioclase porphyritic. The younger type is nonporphyritic and crosscuts the earlier variety.

STRUCTURAL GEOLOGY

The Beardmore-Geraldton Metavolcanic-Metasedimentary Belt is dominated by prominent east-trending faults characterized by ductile-brittle dextral shear zones (Williams 1986). Within the map area, two major deformation zones have been outlined: the Northern Deformation Zone and the Southern Deformation Zone (Figure 015.1). The Northern Deformation Zone represents the eastern extension of the Burrows River Fault (Beakhouse and Chevalier 1983). The Southern Deformation Zone represents the continuation of the Bankfield-Tombill Fault (Horwood and Pye 1955). Both deformation zones are defined by strong planar and linear fabrics, asymmetric structures represented by rotated, boudinaged quartz veins, mesoscopic "Z"-shaped folds, and low angle offsets. All kinematic indicators point toward a dextral sense of movement. A pronounced lineation has developed in the Southern Deformation Zone east of Long Lake. This lineation plunges west at moderate angles and is coaxial with the plunge of mesoscopic "Z" folds.

Reliable stratigraphic facing indicators have been found in the sedimentary units. The southern sedimentary unit is a north-facing sequence. The central sedimentary unit has been folded into a syncline and anticline. The northern sedimentary unit has also been folded into a syncline and anticline (cf. Beakhouse and Chevalier 1983).

Foliation throughout the map area is parallel to the strike of the lithological units. In the southern part of the map area, dips of bedding and foliation are to the south at moderate to steep angles with corresponding north-facing directions, suggesting a largely overturned sequence. Further north, bedding and foliation attitudes become vertical.

Abrupt metamorphic changes across Long Lake, coupled with stratigraphic offsets and contrasts in the aeromagnetic trends (ODM-GSC 1962a), imply that a major northeast-trending fault along Long Lake has been responsible for uplifting the rock units east of the lake, thereby exposing a deeper level of the stratigraphy on the east side of Long Lake.

ECONOMIC GEOLOGY

GOLD

The map area comprises the eastern part of the Beardmore-Geraldton Gold Belt and lies east of the Geraldton gold camp which produced 3 million ounces of gold between 1934 and 1970 (Mason and White 1986). Total production of gold from the Beardmore-Geraldton Gold Belt has exceeded 4.1 million ounces (Mason and McConnell 1982). No mineral production has taken place within the present map area. The Theresa Mine, located approximately 1.5 km east of Abrey Township, produced 4785 ounces of gold from three shafts between 1935 and 1955 (Mason and McConnell 1982).

Between 1934 and 1935, MacFarlane Gold Mines sank two exploration shafts east of Long Lake and south of Abrey Township. Pyrite and chalcopyrite mineralization along with "considerable free gold" had been reported in quartz veins and wall rock (The Northern Miner, September 2, 1937, p.9). Fairbairn (1938) reported "coarse visible gold" from a contact between a feldspar porphyry dike and sheared conglomerate at the MacFarlane West showing. The property was not brought to the production stage.

In the map area, gold mineralization is associated with the two major east-trending deformation zones and the western "nose" of the Croll Lake Stock (Figure 015.1).

Northern Deformation Zone

In the Northern Deformation Zone, in central Houck Township and in central and eastern parts of Oakes Township, irregular gold-bearing quartz veins with associated pyrite, chalcopyrite, and pyrrhotite occur in highly deformed mafic to intermediate volcanic rocks. Grab samples taken by the field party from two sulphide-bearing quartz veins in Oakes Township assayed 1160 and 830 ppb gold (analysis by the Geoscience Laboratories, Ontario Geological Survey, Toronto).

Southern Deformation Zone

Numerous gold showings occur along the Southern Deformation Zone over a distance at 10 km (Figure 015.1). This zone is the eastward extension of the same zone that hosts the Geraldton gold camp.

Pyritiferous quartz-carbonate veins and veinlets occur in strongly sheared polymictic conglomerate, tightly folded lithic wacke, and magnetite iron formation, and can be traced on either side of West Side Bay of Long Lake for a distance of 2 km and width of 1 km. In the same part of the Southern Deformation Zone, numerous pyrite and pyrrhotite mineralized shears crosscut polymictic conglomerate and are also common along coarse-grained feldspar porphyry-conglomerate contacts between Birch Bay and West Side Bay.

Recent overburden stripping by Geraldton Longlac Gold Incorporated in the vicinity of the old Burroughs Syndicate Occurrences (Mason and White 1986) in Coltham Township has exposed several zones of pyrite mineralization. An extensive network of quartz-carbonate veins over a 10 m width is hosted by strongly folded iron formation and siltstone. Pyrite mineralization occurs at quartz vein contacts with iron formation. In another trench 800 m to the east, disseminated pyrite occurs in sheared conglomerate with carbonate, silica, and hematite alteration.

The MacFarlane West showing, south of Abrey Township on the eastern side of Long Lake, is exposed as a pyrite mineralized 0.3 m wide shear with subordinate arsenopyrite and associated quartz-tourmaline veining. Five hundred metres to the east, pyrite mineralization with minor pyrrhotite and arsenopyrite, along with numerous quartz stringers, are ex-

posed over a width of 2 m in strongly Z-folded garnetiferous, hornblende-bearing metasediments.

The Coniagas Occurrences (Fairbairn 1938), east of the MacFarlane showings, consist of highly sheared and silicified wackes and garnetiferous hornblende-bearing metasediments hosting pyrite mineralization with minor arsenopyrite, chalcopyrite, and pyrrhotite.

Numerous quartz-carbonate-tourmaline veinlets are exposed along the eastern shore of Long Lake through the Northern Narrows. The veinlets are hosted by andalusite schist, chlorite schist, and quartz porphyry. One quartz-tourmaline vein (Smith-Elliot Occurrence) in silicified quartz porphyry was reported by Fairbairn (1938) to host visible gold.

Mineral Lake Showings

The Mineral Lake showings in Croll Township consist of an extensive network of quartz-tourmaline veins off the western "nose" of the Croll Lake Stock. The mafic metavolcanic host rocks are locally tourmalinized and brecciated. The quartz-tourmaline veins host pyrite, chalcopyrite, pyrrhotite, and minor molybdenite mineralization. Sulphide mineralization is erratic but appears to decrease in a northward direction from Mineral Lake. Local zones of silicification, albitization, and carbonitization were noted west and southwest of Mineral Lake.

RECOMMENDATIONS FOR EXPLORATION

The two extensive deformation zones within the map area (Figure 015.1) described above are favourable targets for regional gold exploration. Gold showings, some with visible gold, are exposed along both deformation zones.

Gold mineralization at Geraldton is intimately associated with sulphide replacement in banded iron formation (Macdonald 1983a). Iron formation within the map area should be prospected for pyrite replacement of magnetite.

Intensive quartz-tourmaline veining with sporadic sulphide mineralization (cf. Macdonald 1983b) off the western "nose" of the Croll Lake Stock may locally host economic gold mineralization.

A series of electromagnetic conductors (Ontario Geological Survey 1983) in north-central Houck Township should be further investigated for gold and base metals.

ACKNOWLEDGMENTS

Parts of the present map area are situated on Longlac Indian Reserves Nos. 58 and 77. The authors express their appreciation for permission granted by the band councils of both reserves to map on their ground.

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016. Geology of the Birch Lake Area, District of Kenora (Patricia Portion)

G.P. Beakhouse

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Birch Lake area is located 100 km east-northeast of the Town of Red Lake. The area under investigation comprises approximately 700 km^2 bounded by Latitudes 51°16′N and 51°27′N and Longitudes 92°06′W and 92°39′W. Access to the area is by float plane from Red Lake.

Field work completed in 1987 is designed to provide a regional synthesis of the geology of part of the Birch Lake area and builds upon earlier reconnaissance examinations of the Birch Lake greenstone belt (Furse 1934; Harding 1936; Goodwin 1967; Thurston 1986) and recently completed mapping at a scale of 1 inch to 1/4 mile (Good 1985, 1986; Good *et al.* 1986; Beakhouse 1985; Beakhouse and McNeil 1986). In 1987, mapping coverage at a scale of 1 inch to 1/4 mile was completed and some specific geological problems were investigated.

GENERAL GEOLOGY

The general geology of the area has been described previously by Good (1985, 1986), Beakhouse (1985) and Beakhouse and McNeil (1986). The description will not be repeated here. Specific areas and geological problems examined are discussed below.

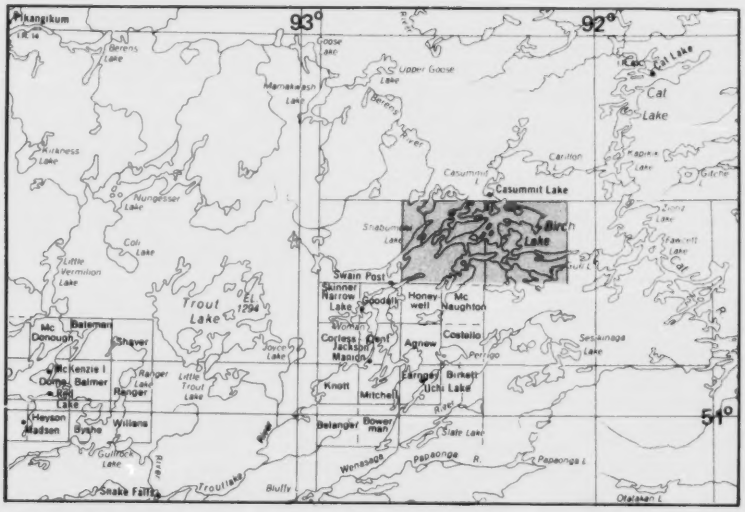
EXIT BAY DEFORMATION ZONE

The existence of the "Exit Bay fault" was originally postulated on the basis of a prominent regional lineament recognizable on Earth Resources Technology Satellite (ERTS) imagery and the recognition of local, intense fabric development and carbonate alteration (Beakhouse 1985). The Exit Bay deformation zone may be a branch of the Swain Lake deformation zone which follows Swain Lake and then trends northeasterly through the large peninsula on the west shore of Birch Lake (Figures 016.1 and 016.2). Swain Lake, Exit Bay and the east-trending arm of Springpole Lake lie along the ERTS-defined lineament but local topographic manifestations of this lineament, such as linear valleys, are not conspicuous in the segment between Swain Lake and Exit Bay.

Zones of strong fabric development are coincident with zones of strong iron carbonate alteration but these are discontinuous and do not form throughgoing features as occurs in the Swain Lake deformation zone. In the area between Swain Lake and Exit Bay, the extension of the ERTS image lineament is parallel to a regional fabric and local deformation/alteration zones, and cuts bedding at a moderate to high angle. At Louwag Lake, stratigraphic units can be traced across the previously proposed fault.

These observations suggest that the dominantly metasedimentary sequence west of South Bay is not cut by a fault connecting the Swain Lake and Exit Bay-Springpole Lake segments of the ERTS-defined lineament. Three alternative explanations are considered possible:

1. The ERTS-defined lineament is due to a deformation zone dominated by pure shear having no significant displacement.
2. The alignment of the Swain Lake and Exit Bay-Springpole Lake segments of the lineament rec-



LOCATION MAP

Scale: 1:1 548 000 or 1 inch to 25 miles

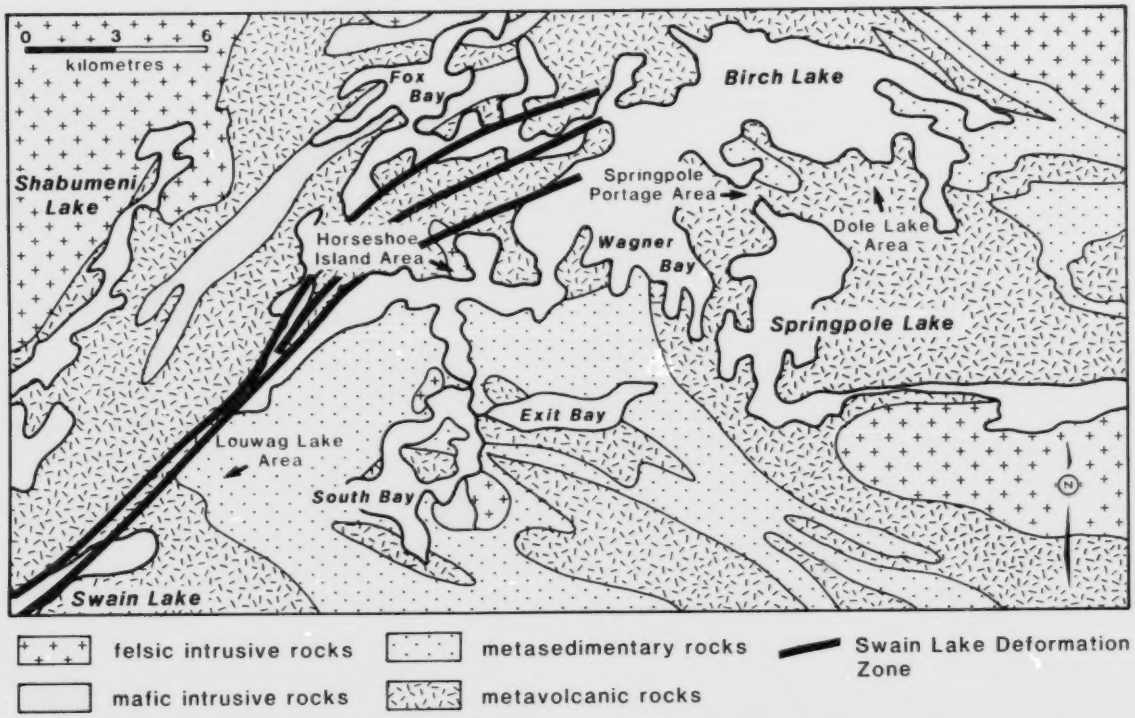


Figure 016.1. *Generalized geological map of the Birch Lake area illustrating the location of areas discussed in the text.*

ognized on the satellite photographs is fortuitous and the two are unrelated.

3. The ERTS-defined lineament represents an early fault that is continuous across the map area but does not have any topographic manifestation between Swain Lake and Exit Bay because the fault is unconformably overlain by metasediments which postdate the faulting.

There is presently little to choose between these various alternatives although 1. is consistent with the regional structural style and 3. is compatible with the high stratigraphic position of those rocks that can be traced across the lineament.

WAGNER BAY AREA

Outcrops in the western part of Wagner Bay were examined to determine the relationship between intermediate pyroclastic deposits and a wacke-siltstone sequence that appeared, on the basis of earlier mapping, to strike in a northerly direction into one another suggesting a possible facies transition (Good, in preparation). Examination of additional outcrops not seen during the earlier mapping confirms this general distribution of lithologies, but bedding orientation is highly irregular. This, together with reversals in top directions, suggests that an originally east-trending contact between the two units has been tightly folded about north-trending fold axes. Bedding orientations are now largely transposed into the northerly trend. This implies that the two units are not necessarily lateral facies equivalents. The timing of this folding with respect to the main regional deformation remains unknown.

SPRINGPOLE PORTAGE AREA

Detailed investigation of a stratigraphically complex area between the north end of Springpole Lake and the south shore of Birch Lake was initiated in 1987. This area is currently the focus of a major gold exploration program being carried out by Gold Fields Canadian Mining Limited.

The area west of the portage between Springpole and Birch Lakes is underlain by a homoclinal, northeast-facing, mafic volcanic sequence with subordinate intermediate tuff and clastic and chemical metasediments. East of the portage, this sequence is overlain by fragmental intermediate metavolcanics including a distinctive feldspar porphyry which has both massive intrusive and coarse pyroclastic facies. Both units are overlain by massive to moderately well-bedded, polymictic conglomerate and arenite.

The conglomerate unit displays a general gradation from a quartz-poor variety, with clast populations suggestive of local derivation at the base, to a more

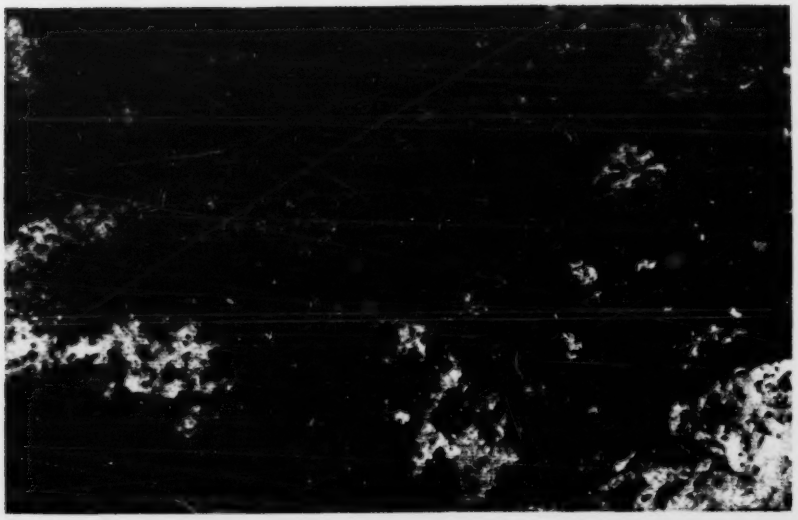
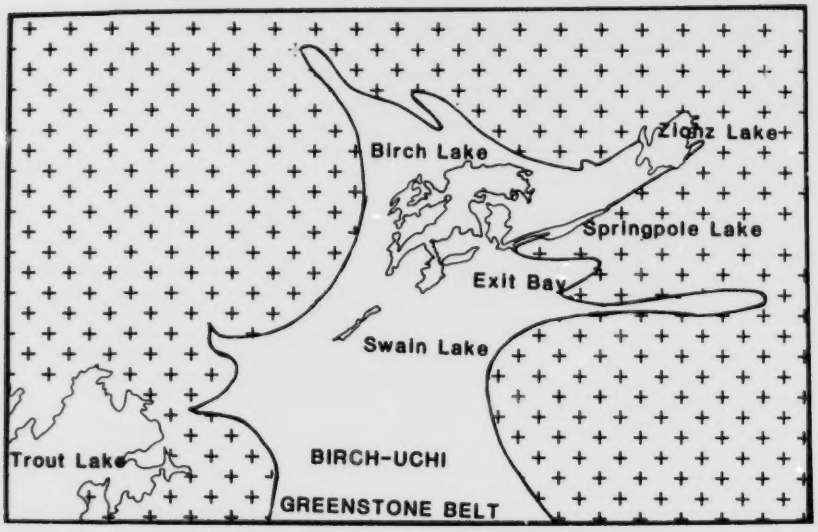


Figure 016.2. *ERTS image of the Birch Lake area.*



heterolithic and quartz-rich variety towards the top. For example, near the entrance to the bay north of the portage, where mafic volcanics are directly overlain by the conglomerate, mafic fragments constitute up to 80 percent of the clasts. Further east, where intermediate volcanics are overlain by conglomerate, intermediate to felsic clasts predominate. These conglomerates are difficult to distinguish from, and may be transitional into, the well rounded, heterolithic volcaniclastic conglomerates that occur in the intermediate volcanic unit. At higher stratigraphic levels, the quartz content of the arenites and conglomerate matrix is higher and the clast populations are more uniformly heterolithic.

DOLE LAKE AREA

Results of two previous mapping programs (Thurston *et al.* 1981; Good, in preparation) suggested significantly different distributions of mafic and intermediate metavolcanics in the vicinity of Dole Lake. Reexamination of this area indicates that mafic metavolcanics are extensive around and northwest of Dole Lake and their distribution is approximately as illustrated by Thurston *et al.* (1981).

SOUTH BAY AREA

Additional traverses southeast of South Bay, within an area previously indicated as being a circular mafic intrusion (Beakhouse 1985), suggests that much of the eastern part of this area is underlain by massive feldspar porphyry of intermediate composition. The feldspar porphyry contains disseminated

sulphides and local iron carbonate alteration and quartz-tourmaline veining. Grades of up to 0.18 ounce gold per ton over 1.5 m have been reported from zones within the porphyry unit (Resident Geologist's Files, Red Lake, Ontario Ministry of Northern Development and Mines).

STRUCTURE

Observations made during the 1987 field season are generally consistent with earlier interpretations (Good 1985, 1986; Beakhouse 1985; Beakhouse and McNeil 1986) of the structure of the area. The main regional deformation (D_2) to have affected most of the greenstone belt is interpreted to be due to the emplacement of large granitoid complexes to the northwest and northeast of the belt. D_2 deformation is responsible for major fold-axial surfaces and deformation zones that are oriented parallel, or near parallel, to the contact with granitoid rocks. Although some deformation zones (e.g. Swain Lake deformation zone, Beakhouse and McNeil 1986) have components of pure and simple shear and can be traced continuously for up to ten or more kilometres, many appear to be principally zones of pure shear (flattening) that occur within particular lithologic units and have limited strike length.

ECONOMIC GEOLOGY

Gold mineralization in the Birch Lake area is associated with disseminated sulphide minerals and/or quartz-carbonate veins. Pervasive iron carbonate alteration, occurring as disseminations and/or veins, is associated with most occurrences. D_2 structures (deformation zones, fold axes, conjugate shears) have played a major role in localizing this alteration and mineralization. Pre-D_2 mafic to felsic intrusions appear to be particularly favourable sites for mineralization. These intrusions characteristically deform in a more brittle fashion than the enveloping volcanic and sedimentary rocks and accommodate less of the strain. Their presence appears to facilitate heterogeneous deformation within the enveloping rocks which enhances permeability and focuses subsequent fluid flow responsible for alteration and gold mineralization. Examples of this situation include the significant gold occurrences on Horseshoe Island and at the Springpole Portage.

ACKNOWLEDGMENTS

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017. Geology of the Horseshoe Lake Greenstone Belt, District of Kenora

L.S. Jensen

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The investigation of the Archean Horseshoe Lake Greenstone Belt represents a one-year project to map a 30 km long and 8 km wide area of metavolcanic and metasedimentary rocks surrounded by granitoid rocks. The purpose of the project is to provide a detailed geological data base for mineral exploration in the area. This report focusses on the lithologies and structural features of the greenstone belt.

The Horseshoe Lake Greenstone Belt is located on the southern margin of the Sachigo Subprovince within the Superior Province of the Canadian Shield, 100 km north-northwest of Pickle Lake. The belt is accessible by float-equipped aircraft on Horseshoe, Kecheokagan and Wapamisk Lakes and by Highway No. 808 which extends north from Pickle Lake to Windigo Lake. The road transects the eastern end of the Horseshoe Lake Greenstone Belt, 160 km north of Pickle Lake, and boats may be launched on the Pipestone River, which permits access to Horseshoe Lake and Kecheokagan Lake. The map area is within the Patricia Mining Division.

In 1960, the Geological Survey of Canada mapped the Horseshoe Lake area as part of a large project that included North Caribou Lake (Carruthers 961). Sage and Breaks (1982) produced maps and reports covering the map area that were completed during a 1972 reconnaissance geological survey covering the Cat Lake-Pickle Lake area.

MINERAL EXPLORATION

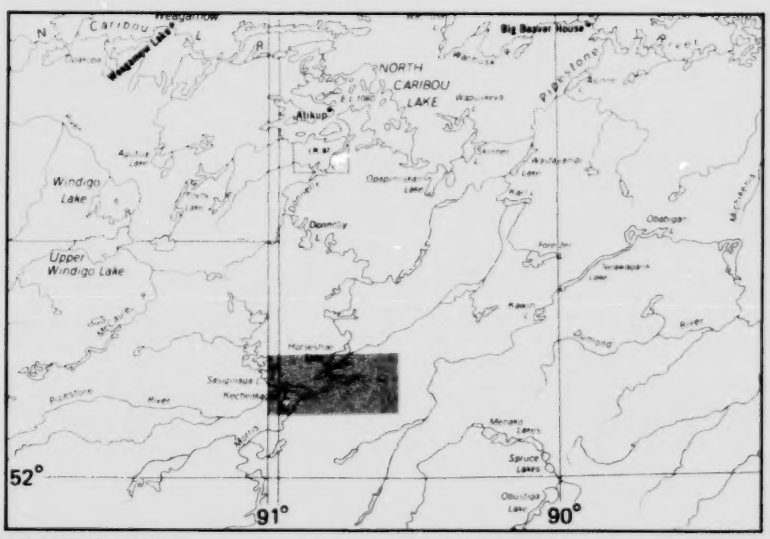
Information concerning the earliest mineral exploration in the Horseshoe Lake area is minimal. Overgrown pits and trenches in the belt, and the discovery of gold mineralization at Upper Windigo Lake in 1928 (Satterly 1941) suggest that prospecting was done in the 1920's. Carruthers (1961) reported that gold mineralization occurred at Horseshoe Lake.

Rio Tinto Exploration Limited carried out an exploration program in 1965 that included ground magnetic and electromagnetic surveys, followed by diamond drilling. From 1971 to 1973, Great Plains Development Company of Canada Limited conducted an airborne magnetic-electromagnetic survey, with additional ground geophysics and diamond drilling. Dome Exploration (Canada) Limited carried out a similar exploration program in 1974, with additional trenching and diamond drilling (Assessment Files Research Office, Ontario Geological Survey, Toronto). Rio Tinto Exploration Limited reported drilling results of 0.12 percent copper over 0.3 m, 0.05 ounce gold per ton over 1 m and 0.06 ounce silver per ton over 0.5 mm. Surface samples as high as 0.2 ounce gold per ton were also reported.

During this year's survey, unreported trenches and signs of diamond drilling were observed by the field party personnel.

GENERAL GEOLOGY

The Horseshoe Lake Greenstone Belt is a 4 to 8 km wide, east-trending, metavolcanic-metasedimentary succession approximately 30 km long. It is bordered by thick granitoid migmatite zones (Figure 017.1) that have been intruded by gneissic to massive tonalite, trondhjemite, granodiorite and syenite. Metamorphism of the supracrustal rocks ranges from upper greenschist facies to lower and middle amphibolite facies. The degree of deformation varies from minor to extreme, depending on the lithology and proximity to major structural features.



LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

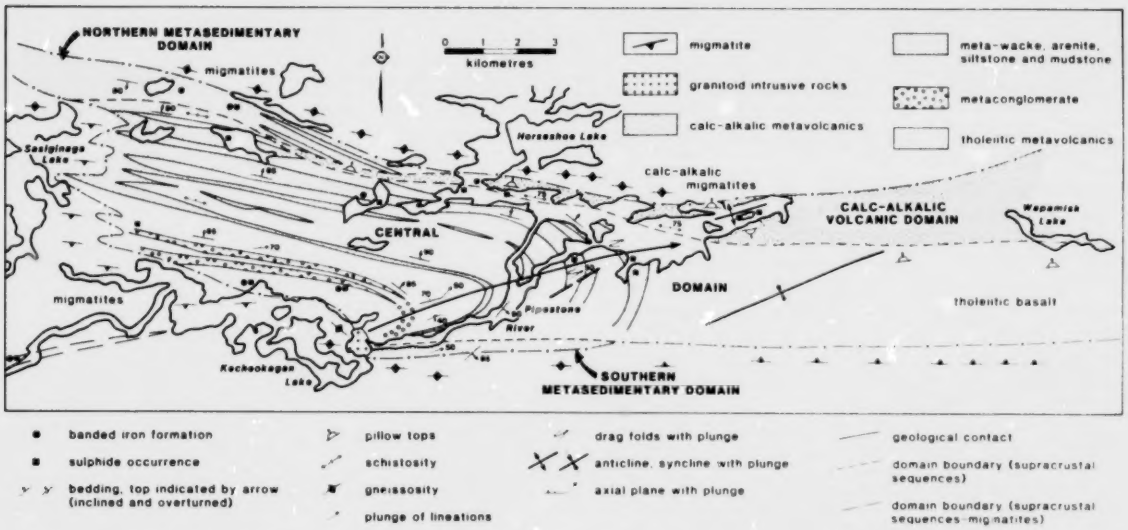


Figure 017.1. *Geology of the Horseshoe Lake Greenstone Belt.*

The Horseshoe Lake Greenstone Belt is composed of four distinct geological domains: the Central, Northern, Southern and Calc-alkalic Domains, which are separated by curvilinear east-trending boundaries, across which lithological and structural changes occur (Figure 017.1). Domain boundaries (discordances) may represent depositional unconformities accentuated by later structural deformation, or boundaries between tectonically juxtaposed groups of rocks that were spatially unrelated at the time of their formation. The Central Domain consists of tholeiitic metavolcanic rocks interlayered with turbiditic metasedimentary rocks. The Calc-alkalic Domain consists predominantly of calc-alkalic metavolcanic rocks, and the Northern and Southern Domains are composed of metasedimentary rocks. The classification of the metavolcanic rocks used in this report is based on field characteristics, and will be refined when geochemical results have been obtained.

CENTRAL DOMAIN

The Central Domain consists of a 3.5 to 4 km thick succession of folded tholeiitic metavolcanic rocks and turbiditic metasediments. The ratio of metasedimentary rocks to metavolcanic rocks decreases from greater than 1:1 north of Kecheokagan Lake, in the western end of the belt, to less than 1:20 near Wapamisk Lake in the eastern end of the belt (Figure 017.1).

The metavolcanic rocks consist predominantly of Mg-rich and Fe-rich tholeiitic basalts. They are coarse- to fine-grained flows, with minor amounts of pillowed lava, pillow breccia and hyaloclastite. These volcanic rocks comprise units that can be traced along strike for several kilometres. The units are separated by metasedimentary rocks of various thicknesses. Some of the coarse-grained rock units may be subvolcanic sills.

The base of each tholeiitic unit consists of coarse-grained, pyroxene-phyric layers that grade upward into medium-grained, equigranular, gabbroic-textured rocks. The central part of the unit can be plagioclase-phyric; the upper part of the unit tends to be diabasic-textured, and shows iron enrichment by being magnetic. The stratigraphically highest tholeiitic volcanic units contain blue quartz, tend to develop granophyric textures, and are the most Fe-rich units in the domain. In places, minor tholeiitic andesite and dacite occur in association with these Fe-rich units.

The metasedimentary rocks of the Central Domain comprise conglomerate, wacke, arenite, siltstone and mudstone, all of which were deposited as turbidites. Chert, limestone and banded iron formation also occur. The clastic metasedimentary rocks form thick units (50 to 500 m) that extend along strike for several kilometres (Figure 017.1), and thin (<3 m) interflow layers within the tholeiitic units. Many of the thick units contain subordinate, thin flows of tholeiitic basalt.

The thick metasedimentary units display an upward progression from pebbly wackes to mature quartzo-feldspathic arenite and quartz arenite. This progression is observed both within thick individual units and in the total volcano-sedimentary succession. Two polymictic, matrix-supported pebble to boulder conglomerates with interlayered tholeiitic basalt comprise the lowermost thick metasedimentary unit (Figure 017.1). The lower of these two conglomerates has a mafic volcanoclastic matrix supporting clasts of white, pumiceous to massive calc-alkalic rhyolite, chert, and a variety of sedimentary and mafic volcanic rocks. The upper conglomerate has a more mature, sandy matrix with clasts of mafic to felsic volcanic rocks and chert, and rip-up clasts of conglomerate, wacke and fuchsite-rich, cherty siltstone. Conglomerate is absent from the stratigraphically higher sedimentary units, and the coarsest

sediments are pebbly wackes and arenite that grade up into thick zones of wacke, arenite, siltstone and mudstone. In the highest units, quartz arenite and chert beds become abundant.

Many of the wacke beds in the thick metasedimentary sequence contain coarse, detrital quartz and feldspar that require a granitic source, and some of the arenites have detrital magnetite grains that are probably derived from underlying Fe-rich tholeiitic basalts or magnetite iron formation. In contrast, the thin, interflow, clastic metasedimentary beds are composed of locally derived, basaltic detritus and contain only minor, distally derived quartz and feldspar.

The chemical metasedimentary rocks in the Central Domain consist of chert, iron formation and a 1 m thick bed of limestone. Iron formation, commonly containing pyrite and pyrrhotite, occurs within some interflow sedimentary units, as well as within the lowermost conglomerate in the lower half of the volcano-sedimentary succession. In the upper half of this succession, the iron formation is interlayered with siliceous mudstone and chert, and in most places is less than 1 m thick. Chert, with or without associated iron formation, is best developed in the upper half of the succession, within some thick metasedimentary units that contain arenite. Ferruginous beds of quartz arenite and chert occur as well in the upper portions of the volcanosedimentary succession in the Central Domain.

The 1 m thick limestone bed is interlayered with thin beds of chert, arenite and wacke near the base of a 400 m thick metasedimentary unit on the south shore of Horseshoe Lake. Carbonated Fe-rich tholeiitic basalt underlies this metasedimentary unit.

CALC-ALKALIC DOMAIN

In the Calc-alkalic Domain (Figure 017.1), the metavolcanic rocks consist of massive and pillowed lavas, interlayered with waterlain lapilli- and ash tuffs of calc-alkalic basalt and andesite composition. Minor dacite tuff occurs in this volcanic succession, and a few calc-alkalic gabbro stocks cut it west of Horseshoe Lake. Except for iron formation, chert and mudstone, some of which is graphitic, there are no metasedimentary rocks within the Calc-alkalic Domain.

The well-developed graded bedding in the andesite tuffs and the presence of iron formation in the succession suggest that the calc-alkalic metavolcanic rocks represent a distal facies of a calc-alkalic volcanic pile.

In the Calc-alkalic Domain, the metavolcanic rocks mostly young to the north, and appear to overlie the north-facing rocks of the Central Domain (Figure 017.1). The boundary between the two domains appears to truncate the upper units in the Central Domain, as well as the basal units of the Calc-alkalic Domain.

NORTHERN DOMAIN

The Northern Domain comprises minor tholeiitic lavas and turbiditic quartzo-feldspathic wackes and arenites, quartz arenites, chert and some pyritiferous, magnetite iron formation. This predominantly metasedimentary package strikes east-southeast and youngs to the south. The tholeiitic lavas occur in the eastern half of the domain (Figure 017.1). The rocks of the Northern Domain are similar to those found in the upper parts of the volcano-sedimentary succession of the Central Domain.

Along the northern side, and at the western end of the Northern Domain, the metasedimentary rocks grade into migmatites. Near the northern contact, migmatitic quartz-arenites develop a mylonitic texture in which quartz grains become severely stretched.

SOUTHERN DOMAIN

The Southern Domain consists of conglomerates with a feldspathic matrix, wackes and siltstones. These were deposited as turbidites that strike 060° and young to the southeast with 80° to 90° dips (Figure 017.1). The succession is formed of 10 to 50 m thick, sharp-based, sedimentary cycles that begin with beds of monomictic, matrix-supported conglomerate, and fine upward into beds of wacke that are followed by siltstone beds. The clasts in the conglomerate are wacke pebbles and appear to be locally derived rip-up clasts.

The contacts of the Southern Domain with the east-trending migmatites to the south and the overturned strata of the Central Domain to the north are unexposed. A mylonite zone located at the east end of Kecheokagan Lake may extend east between the migmatites and the Southern Domain (Figure 017.1).

INTRA-BELT INTRUSIVE ROCKS

A massive, white, muscovite-garnet-bearing granite <1 km in diameter intrudes the metavolcanic and metasedimentary rocks of the Central Domain at the eastern end of Kecheokagan Lake (Figure 017.1). Grey, fine- to coarse-grained, feldspar and quartz-feldspar porphyry dikes and fine-grained mafic dikes, 1 to 10 m wide, intrude the rocks of the Central Domain in the vicinity of the Pipestone River inlet into Horseshoe Lake. A north-northwest-trending diabase dike was located south of Wapamisk Lake.

MIGMATITES

Gneissic migmatites are in contact with the supracrustal rocks of the Horseshoe Lake Greenstone Belt, and have been intruded by granitoid dikes that penetrate only up to 20 m into the greenstone belt. The migmatites appear to have been formed as a result of partial melting of the supracrustal rocks accompanied by penetrative deformation and the injection of some felsic magma. The tholeiitic basalts, quartz arenites and cherts are more resistant to partial melting than are the calc-alkalic basalts and andesites and the other sedimentary rocks and remain as recognizable blocks within the migmatites.

Migmatite is in sharp contact with the tholeiitic basalts of the Central Domain along the north shore of Kecheokagan Lake (Figure 017.1) and is intruded by numerous gneissic granitoid dikes and sills. To the south, 1 to 10 km away from the contact with the greenstone belt, the migmatitic rocks become more homogeneous and are intruded by gneissic to mas-

sive quartz diorite, trondhjemite and granodiorite. Small xenoliths of tholeiitic basalt and interflow sedimentary rocks are preserved within the migmatites, and a narrow, 4 km long slice of tholeiitic basalt, containing interflow metasedimentary rock and iron formation, occurs within the migmatites southwest of Kecheokagan Lake (Figure 017.1).

The migmatite is in gradational contact with the Calc-alkalic and Northern Domains. Only thick beds of quartz arenite and chert of the Northern Domain remain intact within the migmatite. The contact relationships between the migmatite and these two domains are well exposed along the northern margin of the belt (Figure 017.1).

STRUCTURAL GEOLOGY

The metavolcanic and metasedimentary rocks of the Horseshoe Lake Greenstone Belt have undergone two or more post-lithification periods of deformation prior to the formation of the migmatites. The mineral bands and lenticles in the migmatites, and the migmatite contacts with the supracrustal rocks, have easterly trends with subvertical dips. Migmatite-supracrustal rock contacts are oblique to bedding and folding directions in the supracrustal rocks (Figure 017.1). A strong, planar, compressional fabric was developed in the supracrustal rocks subparallel to bedding. This fabric was subsequently overprinted by cleavages and drag folding associated with isoclinal folding. The intersections of this first planar fabric and the cleavage form northeasterly-striking, variously plunging lineations in the Northern, Central and Southern Domains, and northeasterly-striking, near-vertical lineations in the Calc-alkalic Domain. The lineations are, in turn, crosscut by narrow shear zones that do not extend across the boundaries of the geological domains.

The boundaries between the domains are curvilinear, east-trending features that are believed to be in part stratigraphically controlled and in part possibly related to late deformation. They are called discordances in this report and on Figure 017.1 to indicate their uncertain origin. Three of the four domains have distinctive rock assemblages, which possibly were unconformable to disconformable with each other. The deformation present along the domain boundaries may be the result of shortening and transpositioning of the domains into their present configuration (Figure 017.1).

In the Central Domain (Figure 017.1), the supracrustal rocks have been folded about a large anticline. The fold axis trends 070° and dips 65° to 70° to the north-northwest. On the northwest limb of the anticline, north of Kecheokagan Lake, the strata face and dip 80° to 90° to the north. South of the fold axis, the supracrustal succession has a variable strike and becomes overturned with dips as low as 40° to the northwest. Several crosscutting faults in the hinge zone cause parts of the sequence to be repeated southeast of Horseshoe Lake. A complementary syncline, east of the anticline, may occur south of Wapamisk Creek (Figure 017.1). Limited exposure south of Wapamisk Lake contains north-facing pillows within the tholeiitic metavolcanic rocks.

In the Calc-alkalic Domain, the strata dip and face steeply to the north (Figure 017.1). At the east end of Horseshoe Lake, an anticline is defined by the facing of pillowed lavas. The bedding and foliation attitudes of rocks in the Calc-alkalic Domain are parallel to gneissosity in the migmatites to the north, into which this domain grades. West of Horseshoe Lake, the Calc-alkalic Domain forms a wedge between the Central and Northern Domain.

In the Northern Domain, the strata face and dip steeply to the south. Northward, the rocks become more strongly deformed through flattening and stretching of the beds and minerals as the domain grades into the migmatite.

In the Southern Domain, the strata face and dip steeply southeast and contain mineral lineations which plunge to the east and northeast. These structural features are truncated at the east-trending contact of this domain with the migmatite. This contact occurs on strike with a mylonite zone located between the white, muscovite-garnet-bearing granite and the migmatite at the eastern end of Kecheokagan Lake.

The contact between the Central and Southern Domains may be a fault zone under the Pipestone River. However, there appears to be no extension of this fault into the white, muscovite-garnet-bearing granite to the west nor into the strata farther east. The contact may represent an unconformity older than the folding. Mineral lineations in both the Southern and Central Domains plunge to the east and northeast and may indicate that the two domains were deformed together.

ECONOMIC GEOLOGY

Sulphide mineralization in the Horseshoe Lake Greenstone Belt consists of pyrite and pyrrhotite, with or without chalcopyrite and arsenopyrite. Pyrite is ubiquitous in all lithologies. Gossans develop where sulphide mineral concentration exceeds 2 percent. Sulphide mineral concentrations can reach 20 percent of the rock within narrow widths, over considerable strike lengths. Significant occurrences of precious minerals or base-metals were not identified in the field, but the concentrations of sulphide minerals may represent environments favourable for gold and base-metal mineralization.

Gossans are associated with:

1. conglomerate and pebbly wacke that contain 0.1 to 1 cm sulphide clasts
2. cherty siltstone and quartz-arenite that contain disseminated sulphides along narrow bedding and fracture planes
3. chert and iron formation with beds of disseminated to massive sulphide
4. deformation zones with lenticles of sulphide in shear planes
5. disseminated sulphides in mafic dikes
6. feldspar and quartz-feldspar porphyry dikes with disseminated sulphides both within and along the contacts

7. disseminated to massive sulphide within and at the margins of quartz and quartz-carbonate veins and within zones of carbonatization

Several samples from these sulphide occurrences have been submitted for geochemical analyses to test them for gold content.

Detrital gold from older, lode gold mineralization, may be present in the metasedimentary rocks. This possibility is suggested by the presence of vein quartz clasts and sulphide clasts in the metasedimentary rocks. This gold may still be present as detrital grains in the sediments themselves, or may have been remobilized into fracture zones.

Synvolcanic gold and massive base-metal sulphides may be present on the flanks of a calc-alkalic volcanic edifice. Favourable environments are indicated by the presence of calc-alkalic pyroclastic rocks, interlayered with iron formation and graphite- and pyrite-bearing mudstone. The iron formation within the tholeiitic, metavolcanic-metasedimentary successions of the Central and Northern Domains contains concentrations of pyrite and pyrrhotite. The sulphide-bearing beds in the iron formation appear to be both primary and secondary replacing magnetite. This environment is similar to that described by Hall and Rigg (1986) for hydrothermal gold occurrences in the Opapimiskan Lake area. The latter are associated with hydrothermal alteration and sulphidization of iron formation. Similar environments, therefore, may be present in the Horseshoe Lake Greenstone Belt.

The presence of sulphide minerals within sheared rocks, within quartz veins and within zones of carbonatization indicates that metal-bearing fluids were present, and penetrated the supracrustal rocks along fracture zones. Gold may be associated with these sulphide minerals. A favourable environment for this type of hydrothermal gold mineralization may be the hinge zones of the large anticline of the Central Domain and along the domain boundaries where dilatent zones may have occurred.

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018. Alkalic Rocks of the Thunder Bay Area

M.W. Carter

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

This report summarizes the first-year of a regional study of the alkalic extrusive and intrusive rocks in the Shebandowan Belt of the Abitibi Subprovince west of Thunder Bay. It incorporates the results of the last three years' work (Carter 1984; 1985a; 1986a; 1987a; in preparation a, b, c) in the region which forms the study area. Eight weeks were spent in the Summer of 1987 in this area and in immediately adjacent areas to examine rocks of similar type. The field work consisted of detailed examinations of selected areas to study stratigraphic, lithologic, and structural features and to collect rock samples for future mineralogical, petrological, and geochemical investigations.

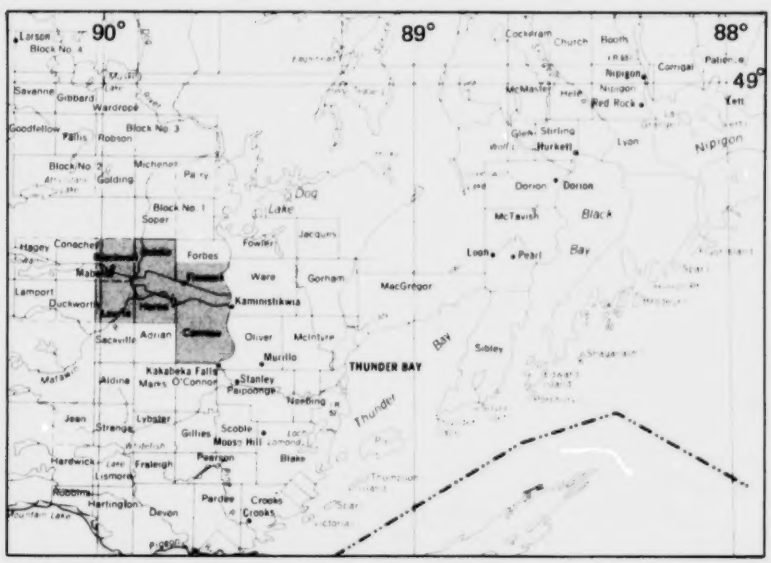
Alkalic metavolcanic and intrusive rocks of the Timiskaming sequence occurring within the metavolcanic Archean terrains at Kirkland Lake are important hosts of gold mineralization (Ploeger 1980; Hodgson 1982). Similar rock types have been found in the Shebandowan Belt west of Thunder Bay (Shegelski 1980, Carter 1984, 1985a, b, c, 1986a, 1987a, b, in preparation a, b, c) and auriferous areas have been located within these rocks in the belt (Carter 1985c, 1986a, in preparation, a, b, c). The Shebandowan Belt and the Kirkland Lake area both form parts of the Abitibi Subprovince. The two areas may have had a similar history. It is, therefore, of economic significance to improve our understanding of the geology of the study area with regard to gold mineralization.

The study area, located about 50 km west-northwest of Thunder Bay, comprises the Townships of Blackwell, Laurie, Goldie, Horne, Forbes, and Conmee and is outlined on the location map. It is traversed by routes 11-17 of the Trans Canada Highway, several forest-access roads, and numerous concession and side roads in the eastern half of the area. The southern parts of the area can be reached via Highway 590 and the Boreal Road of the Great Lakes Paper Company.

MINERAL EXPLORATION

Mineral Exploration in the area has been described by the author (Carter 1984, 1985a, 1986a, in preparation a, b, c) in previous reports and the reader is referred to these publications for information on mineralization associated with rocks other than the alkalic rocks under investigation.

Exploration in the areas underlain by alkalic rocks has been, and is presently being carried out, for gold. At various times between 1967 and 1979, Noranda Exploration Company Limited carried out ground electromagnetic and magnetic surveys in southwestern and west-central Laurie Township. In 1967, the company diamond drilled (66.1 m) one of the many conductors found. In 1968, Phelps Dodge Corporation of Canada Limited carried out a magnetometer survey in an area underlain by alkalic volcanic breccia adjacent to a high-level quartz monzonite-diorite stock in north-central Conmee Township. Magnetic results were described by the company as very erratic. In the time period of March 1972 to March 1973, J.C. Byrne (Caltor Syndicate)



LOCATION MAP Scale : 1 : 1 548 000 or 1 inch to 25 miles

diamond drilled nine holes for a total of 1027 m in south-central Laurie Township.

Since 1985, Noranda Incorporated has been carrying out a gold exploration program including geological mapping, magnetometer and IP surveys, the excavating of trenches, and diamond drilling. So far, 15 trenches have been excavated and 13 holes diamond drilled for a total of 2214.5 m. In 1985 Jalna Resources Limited carried out magnetic and electromagnetic surveys over southern Laurie Township. More recently, in the period 1986 to 1987, Royex Gold Mining Corporation, William Deperry, Kerry Lance, and Melvin Stewart staked several claims in southern Horne Township, an area underlain by alkalic rocks.

GENERAL GEOLOGY

The study area (Figure 018.1) straddles the Quetico-Abitibi (Shebandowan Belt section) Subprovince boundary and extends for about 12 to 17 km southwards into the Shebandowan Belt; the study area is underlain by Archean rocks, in part mantled by Pleistocene and Recent deposits. In this area, interlayered metasediments and metavolcanics occur in two sequences referred to as the Keewatin-type and Timiskaming-type sequences. In the Keewatin-type sequence, metavolcanics comprise an interlayered suite of komatiitic, tholeiitic, calc-alkalic and alkalic rocks, and interflow clastic and chemical metasediments. The supracrustal rocks referred to as the Timiskaming-type sequence in the study area comprise clastic and chemical metasediments and calc-alkalic and alkalic metavolcanics occurring in two parallel bands (Figure 018.1). The volcanic rocks show shoshonitic chemical affinities while the sediments show evidence of alluvial-fluvial depositional characteristics and deposition in fault-bounded, pull-apart basins (cf. Poulsen 1984). The Timiskaming-type sequence thus shows a combination of the attributes listed in Table 018.1, which characterize the Timiskaming environment in greenstone belts throughout the Superior Province. The Archean rocks thus comprise Keewatin-type metasediments and subalkalic and possibly alkalic metavolcanics; Quetico-type clastic metasediments; intrusive ultramafic, mafic, and felsic rocks; unconformably overlying Timiskaming-type calc-alkalic and alkalic metavolcanics and metasediments; diabase and lamprophyre dikes; and a lamprophyric diatreme. These rocks have previously been described in summary reports (Carter 1984, 1985c, 1986a, in preparation a, b, c). The subalkalic metavolcanics of the Keewatin-type sequence are flow dominated whereas the metavolcanics of the alkalic facies are fragmentally dominated.

The alkalic rocks tentatively included in the Keewatin-type sequence occur in northern Conmee Township where they are interlayered conformably with subalkalic, Keewatin-type metavolcanics, strike easterly to southeasterly and, in western Conmee Township, are displaced left-laterally by the Thunder Lake Fault. In southern Horne and Laurie Townships, their strike is more southerly. Both volcanic and major and minor intrusive rocks occur in the alkalic sequence. The volcanic rocks are mainly fragmental and vary from pinkish-green, high-potassium, calc-alkalic rocks (Carter, in preparation b, c) to dark green, mauve, brick-red, and pink-colored alkalic (shoshonitic) rocks. The absence of pillowed structures and the occurrence of bright red hematitization in portions of the flows (and variably developed in the clasts of lapilli-tuffs and tuff-breccias) indicate that these rocks were deposited in a subaerial environment. The pyroclastic rocks are unsorted and unbedded tuff-breccias and lapilli-tuffs, consisting of angular and subrounded fragments, some of which show bleached borders in a dark red or dark green matrix. Both the fragments and the matrix of these rocks are characterized by euhedral, fresh phenocrysts of hornblende and clinopyroxene. The lapilli-tuffs also contain pumiceous fragments and wispy zones interpreted by the writer to be altered pumice. The flows show flow texture marked by the alignment of feldspar laths.

Alkalic rocks occurring as interlayers within the Timiskaming-type sequence (Shegelski 1980; Carter 1984, 1985a, 1985b, 1986a, 1987a, in preparation a, c) were found to be similar to the alkalic (shoshonitic) rocks occurring in the upper part of the Keewatin-type sequence (Carter, in preparation b) as mentioned above. A characteristic feature of the alkalic volcanic rocks of the Timiskaming-type sequence in this area is the occurrence of heterolithic, volcanic debris flows; these grade upwards into bedded pink and brown conglomerates, arkoses, and grey-green and black mudstones which show alluvial-fluviatile characteristics (Parker 1980). Examples of these debris flows are exposed on Highway 11-17 in Blackwell Township about 2 km east of Mabella Road (Carter, in preparation c); on the Inco Limited Shebandowan Mine road south of Shebandowan where Morin (1973) refers to these as conglomerates while Brown (1985) refers to them as breccio-conglomerates; and on Highway 102 about 4.5 km east of Kaministiquia, where they are also referred to as breccio-conglomerates (Brown 1985).

The following comprise the intrusive alkalic rocks (Carter, in preparation b): stocks of pink-weathering, pink and brown feldspar-hornblende porphyry and quartz-feldspar-hornblende porphyry; and a pink, massive, composite hornblende-quartz monzonite and biotite-diopside monzodiorite to diorite stock – the Tower Stock. High-level, apparently alkalic intrusions and volcanic domes, characteristically pink in colour and containing hornblende phenocrysts, and breccia zones containing pumice were observed during the current survey in Conacher and Lamport Townships immediately west of the study area. In those two townships such rocks appear to be more common than in the 1987 study area.

Mauve and brown alkalic lamprophyre dikes containing biotite and augite phenocrysts (which cut the alkalic and subalkalic volcanic rocks in the study area) are considered by the author to belong to the same alkalic magmatic suite of rocks as both the alkalic metavolcanics and stocks (Carter, in preparation a, b).

Many specimens of alkalic rocks from both sequences were collected during the current project for future mineralogical, petrological, and geochemical

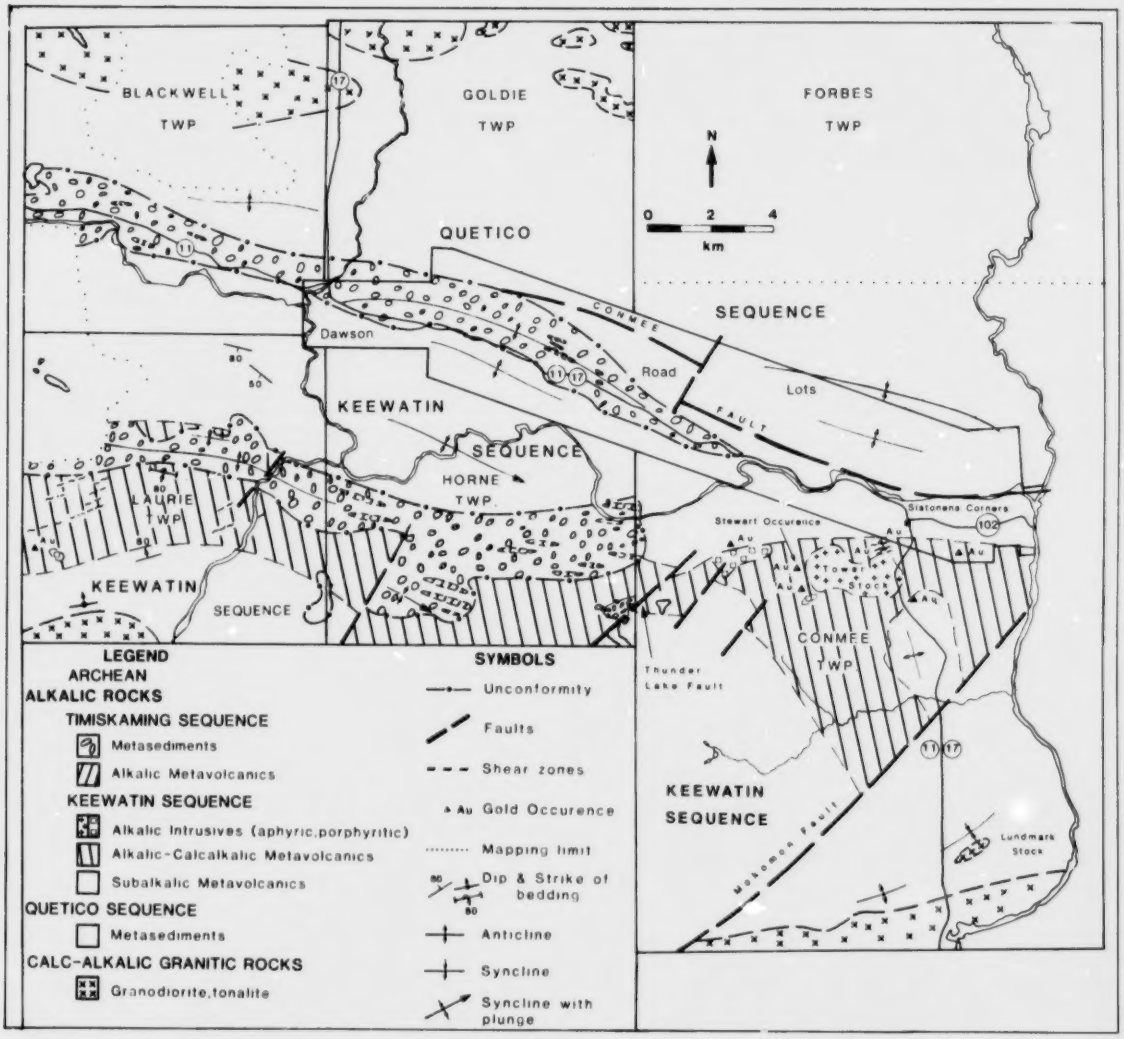


Figure 018.1. *Geological sketch map showing location of alkalic rocks in the Thunder Bay Area.*

investigations. The results of geochemical analyses carried out on these rocks from the previous projects in the study area indicate that the alkalic volcanic rocks and dikes are similar to each other; they comprise absarokite, shoshonite, latite, and toscanite (quartz latite) as well as high-potassium, calc-alkalic andesite and dacite in the classification scheme of Mackenzie and Chappell (1972, figure 3). Rocks of similar types had been previously located in the western part of the area by Shegelski (1980).

A U-Pb zircon age for an alkalic volcanic rock unit from the Timiskaming-type sequence obtained immediately west of the study area yielded an age of 2689 +3/-2 Ma (Corfu and Stott 1986). A minimum age for the older, subalkalic, Keewatin-type volcanic sequence of the same area of 2733±3 Ma has been obtained by Corfu and Stott (1986). Conglomerates in the Timiskaming-type rocks contain alkalic clasts similar to the alkalic volcanic rocks found interlayered with the subalkalic Keewatin-type sequence. The radiometric evidence and the interlayering of alkalic and subalkalic volcanics in the Keewatin-type sequence suggest that the alkalic volcanism commenced in late "Keewatin" time and continued into "Timiskaming" time without an obvious break. Mineral lineations in the calc-alkalic to alkalic, Keewatin-type rocks in southwestern Laurie Township are northwesterly. No preferred metamorphic orientation of minerals could be detected by the author in the alkalic rocks of the Keewatin-type sequence in Conmee Township. The author does not interpret the interlayering as tectonic since no shearing or faulting was observed at the contacts; an attempt will be made in the near future to date radiometrically the

TABLE 018.1. CHARACTERISTICS OF TIMISKAMING SEQUENCES.

Characteristic	Example	Reference
1. Volcanic chemistry		
calc-alkalic	Marda Complex (Australia)	Hallberg *et al.* (1976)
	Welcome Well (Australia)	Giles and Hallberg (1982)
alkalic	Kirkland Lake (Ontario)	Cook and Moorhouse (1969)
shoshonitic	North Spirit Lake (Ontario)	Smith and Longstaffe (1974)
	Oxford Lake (Manitoba)	Brooks *et al.* (1981)
	Shebandowan (Ontario)	Shegelski (1980)
2. Sedimentary depositional environment		
alluvial fan to submarine fan; gravel lag deposits, crossbedded sandstone	Seine conglomerate (Ontario)	Wood (1980)
	Geraldton (Ontario)	Devaney and Fralick (1985)
	Chibougamau (Quebec)	Piche (1984)
	Kirkland Lake (Ontario)	Hyde (1980)
	Casa-Berardi (Quebec)	Pattison *et al.* (1986)
	Crowduck Series (Ontario)	Ayer (1985)
3. Structural environment		
	Rainy River-Seine (Ontario)	Poulsen (1984)
	Kirkland Lake (Ontario)	Hyde (1980)
	Crowduck Series (Ontario)	Sanborn (1986)
	Welcome Well (Australia)	Giles and Hallberg (1982)
	General	Frostick and Reid (1987)

The most general, far-reaching suggestion is that Timiskaming Sequences are deposited in pull-apart basins (Poulsen 1984).

controversial alkalic rocks of the Keewatin-type sequence.

The author believes that the presence of alkalic sequences in the study area; the presence of at least one porphyry-type stock containing copper-molybdenum mineralization–the Lundmark Stock–in southeastern Conmee Township (Carter, in preparation b); and the presence of a possible ophiolitic suite in southeastern Conmee Township (Carter, in preparation b), are all suggestive of a mature, island-arc environment comparable to the Cenozoic Papua New Guinea-Fiji island-arc system (Hughes 1982; Mackenzie and Chappell 1972; Gill 1970; Rodda 1976; Colley 1976). It has been suggested (Joplin 1965, 1968) that shoshonitic rocks are "associated with a region which has recently stabilized or [is] undergoing a late process of stabilization" (Joplin 1968, p.91). Smith (1972) has shown that "high-potassium magmas can be generated in areas of active tectonism and may form part of the island arc 'magmatic' association" (Smith 1972, p.1, abstract).

The results of this summer's field work indicate that some of the alkalic metavolcanics of the study area may form part of the Keewatin-type sequence as previously suggested (Carter 1986a), as well as part of the Timiskaming-type sequence (Figure 018.1).

In the Shining Tree area, a similar association of alkalic metavolcanics interlayered with Keewatin-type metavolcanics appears to be present (Carter 1977, 1980, 1983). The interpretation that alkalic (shoshonitic) volcanic rocks are interlayered with the subalkalic rocks of the Keewatin-type sequence is controversial and further investigations, including radiometric age determinations for the alkalic rocks, are needed to substantiate the observations of the author.

STRUCTURAL GEOLOGY

Structurally, the study area is part of the Shebandowan tectonic belt which is believed to have undergone two deformation events, D_1 and D_2 (Stott 1985), as defined for the region immediately west of the study area. D_1 is the first deformation event which produced a vertical schistosity, upright folds, and westward- and southwestward-plunging mineral lineations observed in the older Keewatin-type rocks. Within the study area, this deformation is associated with tight isoclinal folding along easterly to southerly axes as far east as the northeasterly trending Mokomon Fault (in the southeastern part of the study area), and northwesterly plunging mineral lineations (Carter 1985c, 1986a, 1987b, Chorlton 1987). East of the Mokomon Fault, the tight isoclinal folds trend northeasterly and, in the aureole of the Sundbar-Batwing Batholith, mineral lineations plunge northwesterly (Carter 1986b). The D_1 deformation event occurred at or prior to 2696±2 Ma (Corfu and Stott 1986).

The D_2 deformation event is the second event and occurred after 2689 +3/-2 Ma (Corfu and Stott 1986). The D_2 event affected the northern half of the Shebandowan Belt and produced a regional vertical

foliation, easterly plunging and subhorizontal lineations, and discrete shear zones. It affected the Quetico-type and Timiskaming-type sequences. In the study area, tight, isoclinal, southeasterly trending folds occur in both these sequences, and east-northeasterly plunging mineral lineations were observed in Timiskaming-type metasediments. Short shear zones also cut the Timiskaming-type sequence (Carter 1984, 1985a, 1985b, 1986b).

The D_2 deformation, which involved northwesterly directed, subhorizontal shortening and shearing, is regionally related to large-scale, transcurrent-fault systems that crosscut and define the boundaries of subprovinces (Stott 1985). In the study area the major fault is the Conmee Fault (Carter 1985c, 1986b) which trends northwesterly across the area, marks the boundary between the Quetico and Abitibi subprovinces in the area, and is interpreted by the author to be the easterly extension of the Postans Fault (Morin 1973, map 2267) which is part of the Crayfish Creek-Postans Fault System (Chorlton and Brown 1984, Figure 1, p.202).

The Conmee Fault is associated with intense shearing and deformation of the Quetico-type metasediments in the study area and may be a thrust fault. This fault system is shown by one author as a transcurrent fault with dextral strike-slip movement (Colvine *et al.* 1984, figure 49). This study's author believes that movements on this fault were probably penecontemporaneous with deposition of the Timiskaming-type, alluvial-fluvial sediments and associated alkali volcanic rocks in a contemporaneous, pull-apart basin related to the Conmee Fault. A similar scenario is postulated for the Timiskaming sequence in the Kirkland Lake area (Colvine *et al.* 1984, p.10-18; Toogood and Hodgson 1984), where similar rocks occur related to the Kirkland Lake-Larder Lake Fault.

The study area is therefore believed to have been affected primarily by a continuous period of compression with later extension in the areas underlain by the Timiskaming-type sequence. Brown (1985), however, found no evidence for a second significant period of deformation in the rocks between Shebandowan Lake and Kaministiquia. The two deformation events by Stott (1985) are not widely separated in time, and tends to support the view of a protracted period of compression for the study area.

ECONOMIC GEOLOGY

The economic geology of the study area has been described by the author in previous reports (Carter 1984, 1985c, 1986a, in preparation a, b, c) and is not repeated here. With respect to the alkalic rocks, mineralization is confined to those rocks associated with the upper part of the Keewatin-type sequence rather than with the Timiskaming-type sequence. Until now no mineralization has been observed in the alkalic metavolcanics of the Timiskaming-type sequence. Within the high-potassium calc-alkalic to alkalic (shoshonitic) metavolcanics of the Keewatin-type sequence, gold has been found associated with hydrothermally altered, pyritized volcanic breccias in the aureole of the Tower Stock in northern Conmee Township (Stewart Occurrence). Gold also occurs in small shear zones within these rocks located to the northeast of the Tower Stock, in southwestern Laurie Township, and in southeastern Duckworth Township (Chorlton and Brown 1984; Chorlton 1987).

During the present investigations, two assays were obtained from samples collected 2.5 km south-southeast of Sistonens Corner in Conmee Township (Figure 018.1). One sample yielded 0.02 ounce gold per ton; it was taken from an ankeritized breccia containing pyrite cubes up to 1 mm across and making up about 7% of the rock. The breccia zone is 2 m wide, exposed over a length of about 30 m, and strikes N30°W and dips vertically. The other sample yielded 0.01 ounce gold per ton and was obtained from a grey, massive, feldspar-porphyry dike which is intrusive into the breccia. This dike is about 2 m wide, exposed over a length of about 30 m and contains up to 25% fine-grained, disseminated pyrite. It is cut by ankerite and quartz veins. Both samples contain less than 0.10 ounce silver per ton. (Assays by Geoscience Laboratories, Ontario Geological Survey, Toronto).

SUGGESTIONS TO PROSPECTORS

It is beyond the scope of this report to make recommendations for exploration in the Archean rocks of the study area. This has been done by the author in previous reports (Carter 1984, 1985c, 1986a, in preparation a, b, c). In the following discussion, some recommendations to the explorationist are offered to suggest approaches for work in the alkalic sequences which are the subject of this study.

High-level gold deposits, in a subvolcanic environment, occur in shear zones and breccias in alkalic rocks of the present area and also in Duckworth Township nearby (Chorlton 1987, section 5). Specifically, in the northeastern part of the belt of alkalic rocks in northern Conmee Township, exploration for gold should be carried out in the alkalic breccias in the contact aureole of the Tower Stock. Within this aureole at the western part of the stock, the following occurrences are located (Figure 018.1):

1. an auriferous, pyritized alkalic breccia 0.3 km southwest of the stock's southwestern corner
2. the Stewart Occurrence (Noranda Incorporated, Figure 018.1)
3. two auriferous shear zones 0.5 km northeast of the northeastern contact of the intrusive (Carter 1985)
4. a pyritized volcanic breccia, 0.7 km east-southeast of the southeastern corner of the stock, located during the present investigations

In southwestern Horne Township, exploration activity should be carried out for gold near the southern boundary of the township, 1.7 km east of the southwestern corner of the township. Here silicified felsic rocks containing 30% to 40% pyrite cubes 3 mm across occur associated with a carbonatized shear zone in felsic pyroclastic breccias. A sample taken from the pyritized zone during the current survey and analyzed by the Geoscience Laboratories (Ontario Geological Survey, Toronto) yielded less than 0.01 ounce gold per ton. Exploration should also be carried out in southwestern Laurie Township where a

grab sample from a 15 cm wide quartz vein occurring in an old pit was found to be mineralized with chalcopyrite, bornite, secondary malachite, and azurite in shoshonitic, tuff-breccia. This grab sample yielded 0.14 ounce gold per ton and 0.40 ounce silver per ton (Carter 1987b). Shear zones located in this area during the summer of 1986 (Carter 1987b) should also be prospected for gold.

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019. Hemlo Tectono-stratigraphic Study, District of Thunder Bay

T.L. Muir[1] and C.G. Elliott[2]

[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Graduate Student, Department of Geology, University of New Brunswick, Fredericton.

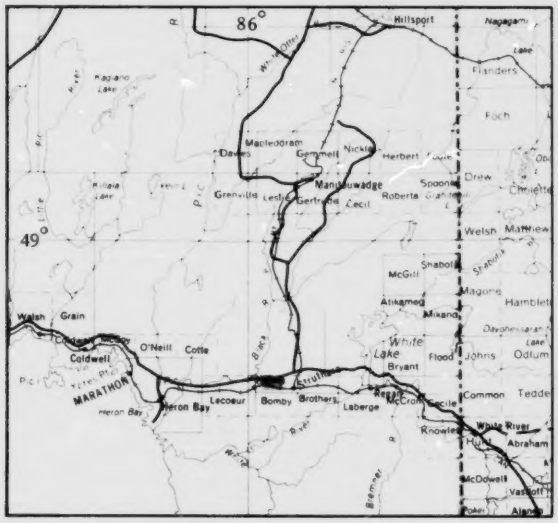
INTRODUCTION

This study is a continuation of a multiyear project intended to provide a detailed geological map and report on the Hemlo Deposit area. During 1987, special emphasis was placed on identifying structural elements and determining their orientations and relative ages. Outcrops along Highway 17 afford a reasonably well-exposed section through the structural hanging wall and footwall of the Hemlo Deposit. A detailed study of highway exposures from the Cedar Lake Pluton to the west end of Finger Lake was undertaken for about five weeks. (This elongate lake running parallel to Highway 17 is incorrectly labelled Cigar Lake on a highway sign. The real Cigar Lake lies to the west-southwest. Another commonly used name, Rule Lake, is also incorrect because a Rule Lake already lies to the southeast. The senior author suggests the name Finger Lake, having derived it from earlier assessment work, and noting the lake's appropriate configuration.) Fill-in mapping of mine-site areas and their environs was initiated. The amount of exposure in these areas is mostly poor because of Quaternary deposits or construction fill, although some access roads have locally greatly improved exposure. Detailed structural measurements were taken and lithological (Figure 019.1a) and form-surface (Figure 019.1b) maps were constructed for the area mapped this field season.

GENERAL GEOLOGY

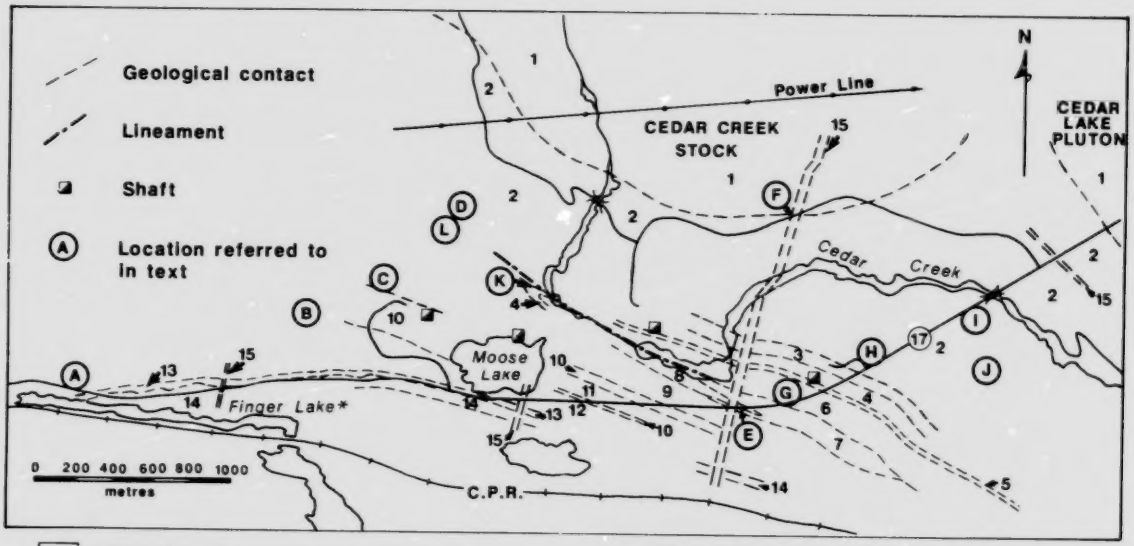
The general geology, lithology, and structural elements of the area, or parts of it, have been described previously by Muir (1982, 1984, 1985a, 1985b, 1986), Patterson (1984, 1986), Hugon (1984, 1986), Brown *et al.* (1985), Quartermain (1985), Valliant *et al.* (1985), Burke *et al.* (1986), Kuhns (1986), Kuhns *et al.* (1986), Valliant and Bradbrook (1986), and Walford *et al.* (1986a, 1986b). Descriptions of lithological units in this summary are condensed.

Variations in characteristics of units along strike, multiple generations of deformation structures, and poor exposure away from the highway preclude significant extension of some units from the highway at this time. A major fold structure, best outlined at locations K and L (Figure 019.1a) (*see* Muir 1985b, 1986; Walford *et al.* 1986a, 1986b), is known to exist but the limb geometry is poorly understood. It can be demonstrated that the fold does not have two limbs in the order of 1 to 2 km long, as indicated by Patterson (1984) and Hugon (1986), because no individual unit can be traced for such a distance. However, the configuration of units, as studied in detail both during this season and previously, does not indicate an obvious alternative solution. A strong possibility is that the lineament, as shown in Figure 019.1a, is a near-axial-planar fault along which displacement has altered a simple fold geometry.



LOCATION MAP

Scale: 1:1 584 000
or 1 inch to 25 miles



1 Granodiorite
2 Metawacke
3 Multicolour-layered metamudstones
4 Interbedded metaconglomerate and metawacke
5 Felsic metavolcaniclastic tuff
6 Multilayered metamudstones and derived schists
7 Felsic metavolcanic and metavolcaniclastic deposits
8 Metamudstone (Garnet-Staurolite-bearing)
9 Feldspathic metasediments
10 Quartz-feldspar Porphyritic Complex
11 Layered metawacke and magnetite ironstone
12 Feldspathic metasediments
13 Feldspathic mylonite
14 Gneissic amphibolite
15 Diabase

Figure 019.1a. *Lithological map of the Hemlo area. Location letters are referred to in text.*

UNIT 1: CEDAR LAKE PLUTON AND CEDAR CREEK STOCK

These granitoid bodies comprise weakly foliated, locally massive, hornblende-biotite granodiorite and microcline-megacrystic hornblende-biotite granodiorite. Based on the exposure along Highway 17, the Cedar Lake Pluton has a possible marginal "phase" (no outcrops with internal contacts were observed) of fine-grained biotite granodiorite which has been intruded by numerous aplite and pegmatite dikes. These dikes are oriented roughly at high angles to the pluton's contact but were not observed intruding the country rocks. The microcline megacrysts have preferentially developed away from the margins of the granitoid bodies.

UNIT 2: METAWACKE

This unit comprises a number of "packages" of metasediments which, as exposed on Highway 17, extend from the western margin of the Cedar Lake Pluton to just west of the David Bell (Teck-Corona) Mine turnoff (Location H, Figure 019.1a). The packages range in thickness from 2 m to greater than 20 m and are characterized by differences in thickness of lithological layering, mineralogical composition, and grain size. Some packages near the Cedar Lake Pluton contain amphibole-rich layers, referred to in the Hemlo camp as "calc-silicate layers". The rocks range from medium to dark grey, are fine to medium grained, and consist of various proportions of feldspar, quartz, biotite, amphibole, and locally chlorite, sericite, and garnet. Locally layers are rich in very coarse sand-size feldspar and biotite. Preferred dimensional orientation of layer silicate minerals ranges from weak to moderate and results in a variable fissility parallel to layering, except near F_2 and F_3 fold hinges. Layers within an east-closing F_2 fold (location I, Figure 019.1a) display grading, repeated compositional variations from quartzo-feldspathic to feldspar+biotite±amphibole, and asymmetrical distribution of laminae within composite layers. These features suggest the presence of incomplete Bouma cycles; therefore, the beds likely were deposited as turbidites. Assuming normal grading, the northeast limb is overturned (*see* Hugon (1984) and Muir (1985b) for more discussion of this fold). Primary sedimentary features, with the exception of local evidence of grading, were not observed in this unit elsewhere.

UNIT 3: MULTICOLOUR-LAYERED METAMUDSTONES

This unit comprises layered rocks with the following generalized characteristics: rusty, buff, light grey, dark grey, and dark green weathered layers; fine-grained textures, except for some amphibole-rich lay-

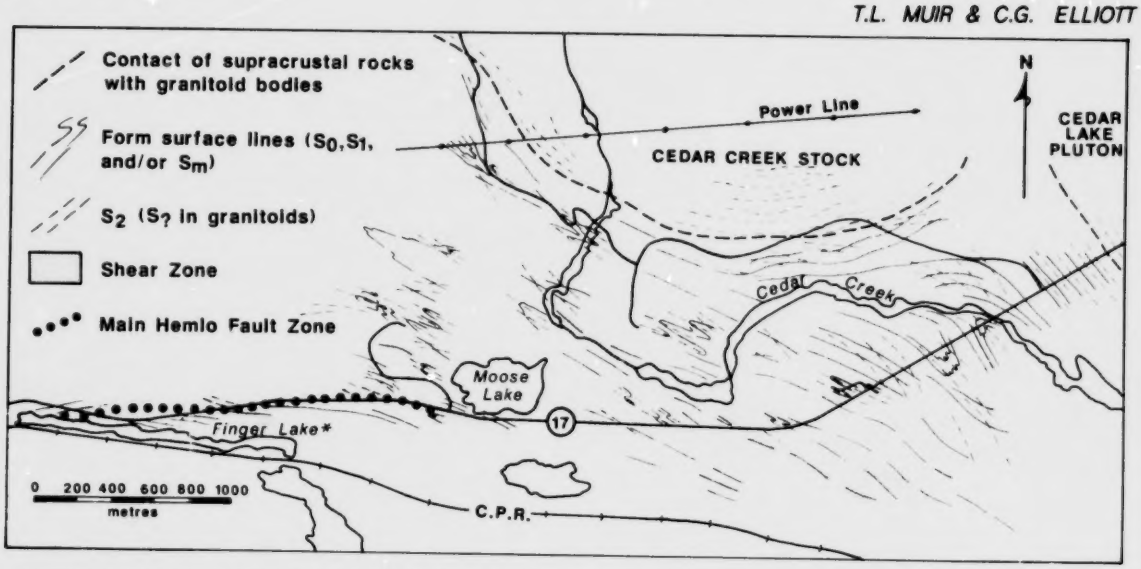


Figure 019.1b. *Form-surface map of the Hemlo area.*

ers; various proportions of feldspar, quartz, and biotite as major minerals, and sericite, amphibole, and locally garnet and staurolite as minor minerals; layer thicknesses ranging from 1 to 4 cm; amphibole-rich ("calc-silicate") layers also containing various amounts of feldspar and locally garnet; and preferred dimensional orientation of biotite and sericite to produce a schistosity parallel to S_1 and/or S_2.

Much of the layering is well defined and is interpreted to be a modification of primary compositional layering (bedding), although no unequivocal primary sedimentary structures were observed. Feldspar-rich layers may have been derived from reworked, tuffaceous material. The amphibole-rich layers may have been derived from chemically deposited material or terrigenous rain in quiescent periods during sedimentation. It is interesting to note that the supracrustal rocks in the map area contain very few ironstone or iron-formation units, but that iron-rich amphibole (calc-silicate) layers are common.

Unit 3 has locally undergone feldspathization (an alteration process which generally also results in the removal of biotite), particularly where the rocks have a more conspicuous, closely spaced schistosity and/or are sheared.

UNIT 4: INTERBEDDED METACONGLOMERATE AND METAWACKE

A poorly exposed, approximately 65 m thick, unit of interbedded metaconglomerate and subordinate metawacke can be traced from about 1 km southeast of Highway 17 to about 1.5 km northwest of the highway. Individual conglomerate units are matrix supported and generally polymictic. Clasts range from unsorted to moderately well sorted, and granule to cobble size, and may be dominantly of one or two lithic types. The most common clast type is feldspar porphyry; the second most common type is biotite or biotite-chlorite schist. Quartz-phyric clasts are uncommon. Very fine grained feldspathic lenses (clasts?) are locally present and are similar to some feldspathized rocks closer to the Hemlo Deposit.

Individual wacke units tend to be dark grey and relatively coarse grained, commonly with coarse-grained feldspar crystals. The matrix of the metaconglomerate and metawacke, and the fragments rich in biotite, are well foliated and locally show dextral shear fabrics.

UNIT 5: FELSIC METAVOLCANICLASTIC TUFF

This unit is poorly exposed on Highway 17 and was observed in only three other small outcrops over a strike length of 1.2 km. The unit displays rusty weathering, is feldspar rich, and crudely layered (2 to 6 cm thick). It also contains sericite (mostly on discrete planes of schistosity), pyrite, minor biotite, and sparse, small quartz crystals. Fine- to very fine grained quartz may also be in the matrix. Because of the characteristics of the layering, the presence of quartz crystals, the overall feldspathic composition with no appreciable potassic feldspar, and the association with metawacke and metaconglomerate, this unit is interpreted to consist of subaqueously deposited tuffaceous material.

UNIT 6: MULTILAYERED METAMUDSTONES AND DERIVED SCHISTS

This unit, as exposed on Highway 17, consists, in its structurally upper part, of layered (2 to 5 cm thick) metasediments. These layers consist dominantly of feldspar-biotite, biotite-feldspar, feldspar, or amphibole. Quartz is present in varying amounts in the first three types, and garnet is locally present in the biotite-bearing layers. Proceeding structurally lower in the section (to the west-southwest), the rocks become coarser grained and schistose, and contain additional minerals such as muscovite, and porphyroblastic anthophyllite, sillimanite, staurolite, and possibly cordierite (as completely retrograded lenses up to 3 cm long). The layering is recognizable even where it becomes more diffuse. The amphibole-rich layers display boudinage and have reaction rinds up to 2 cm thick along their margins. In the core of this zone of schists, refolded folds, now isoclinal, are

present along with shear fabrics (s, c, c') giving a dextral sense of shear. It is interpreted that local hydrothermal alteration of sedimentary rocks produced compositions in layers which were conducive to the development of the above porphyroblasts. These metasediments initially may or may not have been pelitic.

Farther west, the grain size decreases, the porphyroblasts consist of garnet and staurolite, the amphibole-rich layers become sparse, and the shear fabric is locally less pervasive. It is here that the presence of pyrite produces a rusty coating on weathered surfaces. For the purposes of this summary, the Barren Sulphide Zone (colloquially known as the Sucker Zone) is included in this unit.

UNIT 7: FELSIC METAVOLCANIC AND METAVOLCANICLASTIC DEPOSITS

This unit comprises a variety of lithologies which resulted from both primary and tectonic processes. The structurally upper (northeastern) part of this unit consists of rocks very similar to Unit 5 (felsic metavolcaniclastic tuff). The main differences are a greater abundance and general coarser size of quartz crystals, thicker layering (3 to 10 cm), and more widely spaced planes of schistosity. Structurally lower in the unit there are examples of quartz-feldspar-phyric pyroclastic rocks displaying crude layering (>0.5 m) best defined by differences in abundance and distribution of lapilli-size fragments. Elsewhere, parts of the unit are best described as felsic, quartz-feldspar porphyritic rocks of undetermined origin. In these cases, a more pervasive schistosity has an anastomosing pattern which either overprints, or emulates, a fragmental rock. At location E in Figure 019.1a, the rock appears to have a mylonitic fabric and has undergone some potassic alteration. The term "mylonitic" is used here as a field-mapping term and requires petrographic work for substantiation. There are numerous, 3 to 20 cm long lenses in this part of the unit but it is unclear whether these were primary fragments. Moderately to highly flattened quartz eyes are abundant.

UNIT 8: GARNET-STAUROLITE-BEARING METAMUDSTONES

This unit in many aspects is similar to Unit 6; indeed, the two may be one and the same. Layers ranging from light to dark grey are 2 to 25 mm thick and are locally attenuated. Locally, amphibole-rich layers ("calc-silicates"?) consist of numerous boudins. Garnet and staurolite porphyroblasts display clockwise rotation on horizontal surfaces. Staurolite crystals are up to 12 mm long. There appear to be small fibrolite (sillimanite) lenses with splaying terminations.

The rocks of this unit at location E (Figure 019.1a) may be mylonitic. They exhibit F_2 folds and F_3-related dextral shear fabrics. To the west, Unit 8 is more schistose and contains more biotite and muscovite.

UNIT 9: FELDSPATHIC METASEDIMENTS

This unit consists of well-layered (1 to 4 cm thick), light to dark grey weathering rocks with some irregularly distributed, amphibole-rich layers. Sparse garnet is locally present. The layering, besides being defined by colour differences, also reflects grain size and mineralogical differences. Although no primary sedimentary structures were observed, the layering is interpreted to be derived from deformed bedding.

Rocks northwest of Highway 17, tentatively interpreted to be part of this unit, are locally feldspathized, which hampers the delineation of a clearly defined lithostratigraphic unit. The bulk of these metasediments, by their dominant feldspathic mineralogy, may have been derived from volcanic material of felsic to intermediate composition.

UNIT 10: QUARTZ-FELDSPAR-PORPHYRITIC COMPLEX

This name, as used previously (Muir 1986), defines what is likely a composite unit comprising many subunits. On Highway 17, the easterly subunit consists of variably altered, strongly deformed, felsic to intermediate, quartz-feldspar-porphyritic rocks displaying macrolayering (1 to 3 m thick). Within the layers, minor to abundant lenses having felsic or intermediate compositions display a variety of grain size, texture, and mineralogy. Part of this unit is mineralized and equates with the up-dip projection of the main ore zone. The westerly subunit on Highway 17 is similar and is the up-dip projection of the lower ore zone.

The main part of Unit 10, northwest of Moose Lake (Figure 019.1a), is composite. Heterolithic, pyroclastic rocks are locally present, as are sericitic, quartz-feldspar-porphyritic schists. Locally, small to extensive patches of these rocks display feldspathization and pyritization. Schistosity is penetrative, pervasive, and defined by closely spaced planes of sericite which have developed an anastomosing pattern around quartz and feldspar crystals. Dextral shearing is locally evident.

UNIT 11: LAYERED METAWACKE AND MAGNETITE IRONSTONE

This unit is characterized by irregularly spaced and distributed, 5 to 10 mm thick, magnetite-rich layers, with or without considerable amphibole. Some of the layers can be traced for 10 m. The matrix to the layers is poorly to moderately well layered and consists of biotite and feldspar with sparse, local garnet. Where poorly defined, the layering is transposed. No primary sedimentary features were observed. This unit has some characteristics similar to rocks just northwest of Unit 13. However, lithological differences between those two rocks, and their tectonostratigraphic position (Figure 019.1a), presently preclude correlation.

UNIT 12: FELDSPATHIC METASEDIMENTS

Only the structurally lower part of this unit is exposed on Highway 17. It consists of moderately to well-layered rocks (0.5 to 5 cm thick) of varying grain size and mineralogy, which accounts for the variation in

light to dark grey weathered layers. There are irregularly spaced, relatively amphibole-rich layers as well.

In some cases, there are distinctive layers. One such layer (up to 10 cm thick) consists of feldspar-rich and feldspar-porphyritic lenses in a schistose matrix of biotite and possibly sericite. This layer borders the structurally upper contact of one of two gossans. Some layers in Unit 12 display intrafolial F_2 folds. The bulk of these metasediments, by their dominant feldspathic mineralogy, may have been derived from volcanic material of felsic to intermediate composition.

UNIT 13: FELDSPATHIC MYLONITE

This unit extends, as presently defined, from Moose Lake to Finger Lake. It consists of discontinuous and streaky (up to a few metres long), thinly to thickly laminated (1 to 10 mm), feldspathic rocks. There is no well defined contact between Units 12 and 13 south of Moose Lake.

The thicker laminations, not everywhere present, have similarities to some of the layers within Unit 12. The thinner laminations are common and have a "core" of mafic minerals with margins of felsic minerals on either side. These thinner laminations are likely tectono-metamorphic in origin. Laminations within the feldspathic mylonite are essentially parallel to the S_2 and/or S_1 fabric in units adjacent to the ill-defined north boundary of Unit 13.

Whereas petrographic work is necessary to confirm the origin of the layering, the term "mylonite" has been used as a field term. The nature of the protolith of this rock is equivocal. However, there are feldspathic metasediments in the area, as well as feldspathic volcaniclastic rocks northeast of location 'C' (Figure 019.1a) (*see also* Muir 1985b), which may provide examples of possible protoliths.

UNIT 14: GNEISSIC AMPHIBOLITE

This unit extends from southeast of Moose Lake to Finger Lake (Figure 019.1a) and is an extension of a pillowed, mafic volcanic unit which can be traced at least 3 km farther to the west. The unit thins somewhat from west to east and extends for at least 1.5 km farther to the southeast than shown in Figure 019.1a (Burke *et al.* 1986). Although the mafic-rich layers locally appear to be selvages, the rocks are considerably deformed, and no primary volcanic features were seen within this unit as shown in Figure 019.1a.

The gneissic amphibolite within the map area ranges from locally schistose, fine grained, quartz-feldspar-epidote-veinlet-bearing amphibolite with anastomosing fractures, to a quartz-feldspar-epidote-bearing, lensoid amphibolite with a gneissosity largely defined by modal differences in amphibole, feldspar, and locally biotite or epidote. The veinlets are parallel or subparallel to gneissosity and are generally considerably deformed, some more so than others.

Within the structurally uppermost 10 m of this unit are several mafic dikes of picritic basalt composition. The dikes have been the locus for considerable shearing, and some alteration, within the Hemlo Fault. They are locally altered to actinolite-, chlorite-, and talc-rich schists. Locally within the zone of dikes, the gneissic amphibolite wall rocks have been altered to actinolite. There are also several deformed, felsic to intermediate dikes of several different ages within this zone. The gneissic amphibolite within at least the structurally upper part of the unit is mylonitic.

UNIT 15: DIABASE

These rocks are likely Late Archean to Early Proterozoic in age and postdate all ductile deformation. They occur as dikes up to about 50 m thick which have chilled margins and generally medium or coarse-grained centres. They predate some stages of brecciation which may be correlative to brittle-style, layer-parallel breccias (*see* "bedding-planar breccias" in Muir (1986), and "Fourth Generation Structures", this report).

STRUCTURAL ELEMENTS

FIRST-GENERATION STRUCTURES

The earliest deformation structures yet recognized are isolated folds (F_1), and layer-parallel, disrupted zones. F_1 folds (Figure 019.2a) have been noted at the so-called "Back 40's" outcrop near the Page-Williams Mine waste pile (location D, Figure 019.1a), in the nose of the Cedar Creek fold (location I, Figure 019.1a), and near the Cedar Creek Stock on the approach to the Golden Giant Mine (location F, Figure 019.1a). The folds are small scale and isoclinal, are typically confined to isolated horizons, and have been refolded into interference patterns by second- and third-generation folds (F_2 and F_3). All F_1 folds are overprinted by a cleavage displaying differentiated layering (S_2). A doubly plunging F_1 fold at the "Back 40's" outcrop (Photo 019.1) appears to be a sheath fold, but the three-dimensional exposure necessary to confirm this interpretation is lacking. It is also possible that the structure is an interference pattern produced by multiphase folding prior to F_2.

No penetrative axial-planar fabric has been recognized in the closures of F_1 folds. F_1 folds are tight to isoclinal, however, and a widespread, layer-parallel-preferred orientation of minerals is parallel to F_1 axial surfaces. For this reason, and because the regional distribution of F_1 folds is not known, lithological layering in the map area is designated S_1, except where primary depositional structures have been recognized (S_0), or where the layering can be identified as S_2, or as S_m (mylonitic layering).

Other early structures are the layer-parallel disrupted horizons at the "Back-40's" outcrop. The best exposed of these is a 2 m wide unit that Muir (1985b) traced on both limbs of a large-scale F_2 fold closing to the southwest of the "Back 40's" outcrop (*see* Walford *et al.* 1986a, 1986b). The disrupted horizon contains remnants, up to 1 m long, of layers with varying lithologies in a rusty, laminated matrix. Both remnants and laminae are now largely oriented parallel to the S_2 fabric. Some layer fragments are isoclinal F_1 folds, and interference patterns occur in the matrix laminae where F_1 isoclines have been overprinted by F_2 folds.

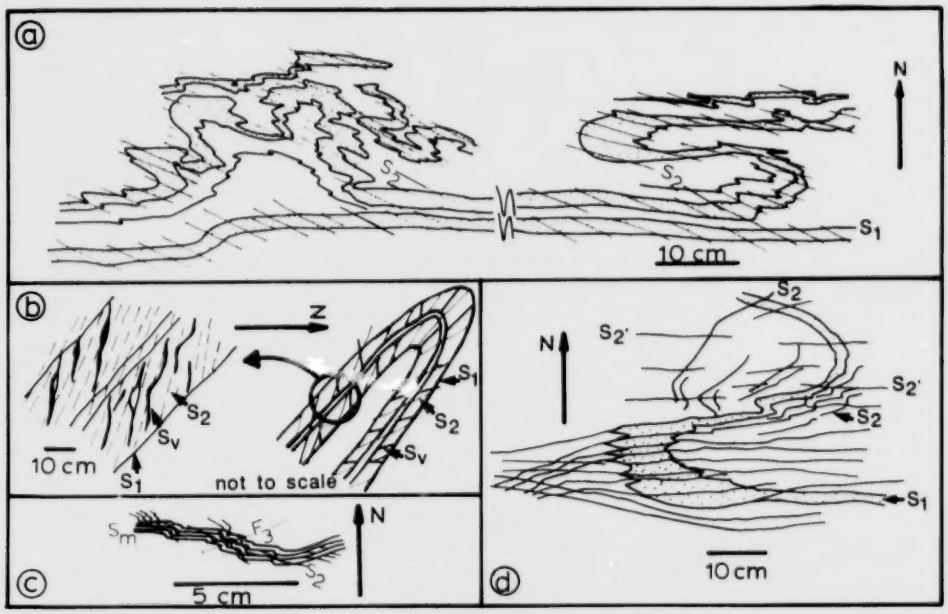


Figure 019.2. *Field sketches of F_1 and F_2: a) F_1 folds at location F, Figure 019.1a. All folds are in the same layer and are overprinted by S_2. b) The relationship between wispy differentiated layering (S_2), veinlike layering (S_v) and S_1 in an F_2 fold. The sketch on the left is from the southeastern limb of the Cedar Creek fold (location I, Figure 019.1a). The diagrammatic sketch on the right represents relationships observed near the David Bell Mine site road turnoff (location H, Figure 019.1a). c) S_2 oriented clockwise from mylonitic layering (S_m), and crenulated by F_3. Highway 17 north of Finger Lake. d) Fold with S_2 axial-planar-differentiated cleavage overprinted by a S_2 cleavage of the same style. The structure is inferred to have formed by progressive sinistral shear. Stippled layer is S_1 and is part of a larger S fold. Highway 17 at the northwestern end of Finger Lake.*

Photo 019.1. *Doubly plunging F_1 fold which may be a sheath fold. It is overprinted by S_2. Location D, Figure 019.1a.*

Photo 019.2. *First-generation, layer-parallel-disrupted horizon which terminates along strike in an F_2 fold. The termination appears to be a folded, low-angle, normal or reverse ramp. Location D, Figure 019.1a.*

The disrupted horizons are characteristically concordant along one margin, and slightly oblique to local layering along the other. The concordant to slightly discordant nature of these units, and the restriction of F_1 isoclines to isolated horizons (Photo 019.2) suggests that first-generation structures were formed by differential movement subparallel to layering. No megascopic first-generation structures have been recognized, and it is not known to what extent they might contribute to the overall geometry of the Hemlo Belt.

SECOND-GENERATION STRUCTURES

The major megascopic structures in the Hemlo Belt are second-generation folds (F_2) (Figure 019.1a). Outcrop-scale F_2 folds (Photo 019.3) are widely distributed, and are characteristically isoclinal. The axial-planar foliation (S_2) is a pervasive, differentiated layering, which locally obliterates traces of S_0 and S_1 layering. S_2 is defined by 1 to 10 mm thick quartz+feldspar±mica±amphibole segregations which can be closely spaced and laminar, or spaced 5 to 10 cm apart. $S_2$is enhanced by, and, in some lithological layers, is defined by a preferred dimensional orientation of inequant grains. The cleavage generally has a wispy appearance, and no given S_2 lamination is traceable for more than a few decimetres. The S_2 fabric is most easily recognized near F_2 closures where it is oblique to S_0 or S_1 layering. On the limbs of F_2 folds, S_1 and S_2 are transposed, and gross compositional layering is paralleled by feldspathic laminae with millimetre- or centimetre-scale spacing.

Some F_2 folds appear to have a composite axial-planar fabric in which two types of compositional layering fan about the fold nose (Figure 019.2b). This is best exposed in the west-closing fold on the east side of the approach to the David Bell Mine where it meets Highway 17 (location G, Figure 019.1a). Here, quartz-feldspar-amphibole segregations or veinlets, restricted to single layers, are oblique to the more

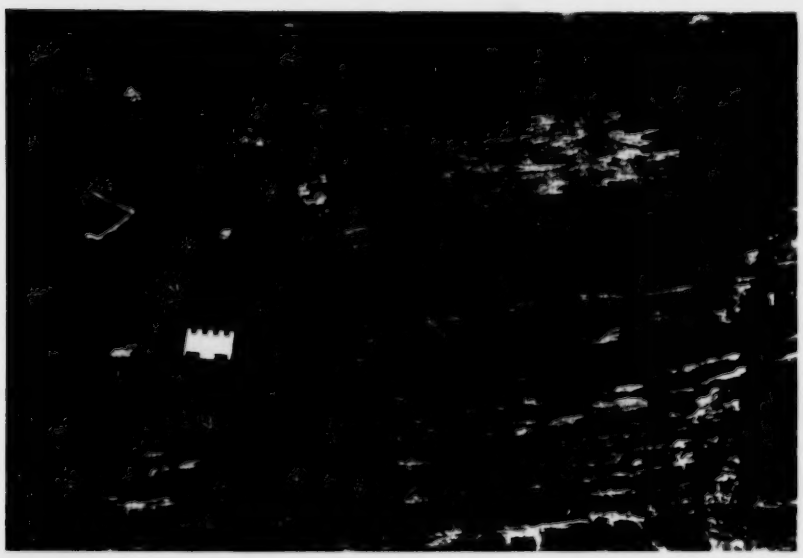


Photo 019.3. *F_2 fold at the Heritage outcrop (location C, Figure 019.1a) with a well-developed, axial-planar-differentiated cleavage (S_2).*

typical S_2 cleavage which characteristically displays wispy compositional layering. The veinlets, however, have a systematic geometric relationship to both the F_2-fold closure and the typical S_2 fabric; the veinlets are oriented clockwise to both S_1 and S_2 on the northeastern limb of the fold, and are counterclockwise to S_1 and S_2 on the southwestern limb. The segregations or veinlets are offset across traces of the wispy S_2 fabric and thus must predate it. It is inferred that the veinlets initially formed at a high angle to layering (perhaps during layer-parallel shortening (Gray 1981)), and were either reactivated as shear planes during F_2 folding, or were offset by removal of material along the trace of the wispy S_2 cleavage.

Large-scale F_2 folds in the Hemlo area, described by Muir (1982, 1985b), Patterson (1984), Hugon (1984), and Guthrie (1984), include the fold set just west of Cedar Creek on Highway 17 (location I, Figure 019.1a), and the large northwest-facing closure north of the Page-Williams Mine (location K, Figure 019.1a) for which no paired, southeast-facing fold closure has been found.

Orientation data for S_1 and S_2 north of the Hemlo Fault (hanging wall) suggest that this area defines a large-scale, S-shaped fold, which may be the north limb of a larger-scale, west-closing, F_2 fold. The S_2 fabric is oriented predominantly clockwise from S_1. Where the asymmetry of mesoscopic F_2 folds can be determined, it is most frequently S-shaped, or equivalent to sinistral folds. North of Finger Lake, the S_2 cleavage is clockwise from S_1 and can be traced from north to south into what is interpreted to be a mylonite zone. Within the mylonite, S_2 is either parallel to the mylonitic layering (S_m) or is oriented clockwise from it in isolated, biotite-rich fragments (Figure 019.2c). Scattered, S-shaped F_2 folds are coplanar with the mylonitic fabric. One isoclinal fold with axial-planar-differentiated layering (S_2), defined by thin seams of pink, feldspathic material, is a refolded sinistral fold overprinted by an apparently identical axial-planar fabric (S_2) (Figure 019.2d). This suggests F_2 folds may locally belong to more than one generation, and that their formation was part of a progressive deformation which involved a component of sinistral shear.

There is a prominent intersection lineation (L_2) throughout the Hemlo Belt which can locally be demonstrated to be the S_1-S_2intersection. This lineation is locally parallel to the long axes of elongate-mineral aggregates, suggesting a component of elongation parallel to F_2-fold axes. West of the Page-Williams Mine along Highway 17, undeformed tourmaline has grown in small rosettes, or is aligned parallel to L_2 and is inferred to have grown passively in the pre-existing L_2 fabric. L_2 is folded by mesoscopic F_3 folds and thus plots along small circles in stereographic projection. Along Highway 17, L_2 plunges shallowly towards the southeast near the margin of the Cedar Lake Pluton, becomes steeper and then shallower, passing through the horizontal near the David Bell Mine (Location H, Figure 019.1a), and plunges approximately 45° NW on the Page-Williams Mine property and along the Hemlo Fault. Where the orientation of mesoscopic F_2-fold axes can be determined, it is parallel to the L_2 lineation.

THIRD-GENERATION STRUCTURES

Structures that overprint F_2 folds, S_2 cleavage, and mylonitic laminae (S_m) include: widespread, mesoscopic Z-folds (F_3); an east-trending fabric (S_3) which may be defined by either preferred dimensional orientation of primary or metamorphic minerals, or by a crenulation cleavage; quartz rods; and mineral lineations.

F_3 folds form open "Z" and rare "S" shapes and typically nucleated on boudin necks (Figure 019.4b) and quartz rods (Figure 019.3d). They generally plunge 40° towards the east and have east-trending axial surfaces. The nature of the axial-planar cleavage (S_3) depends on the local host-rock lithology and habit of any metamorphic minerals that might be present. Even where F_3 folds cannot be recognized, S_3can be identified as a steeply dipping, east-trending fabric oriented counterclockwise to S_0 and S_1.

The largest F_3 fold observed is a refolded F_2 fold found immediately northeast of the Barren Sulphide Zone (location G, Figure 019.1a), in a brittle-ductile, dextral shear zone. The F_3 synform-antiform pair has an axial-planar schistosity in which metamorphic anthophyllite and sillimanite are aligned. The long axes of minerals lie parallel to east-plunging F_3 axes in fold noses, but are horizontal within the limbs of F_3 folds. A west-plunging F_2 fold is overgrown by this mineral lineation. Elsewhere, garnet and staurolite up to 4 mm in diameter have overgrown the S_2 fabric, and where F_3 Z-folds have developed they show dextral (clockwise) rotation.

FOURTH-GENERATION STRUCTURES

Widespread brittle-ductile and brittle structures are associated with and overprint F_3 folds. Dextral s-c fabrics and shear bands (c') are found in layer-silicate-rich horizons such as near the Barren Sulphide Zone (location G, Figure 019.1a) and the phyllonitic, chlorite-actinolite-talc schist within the Hemlo Fault. This schist predominantly records the latest, dextral, movement on the Hemlo fault. Folded mafic and felsic dikes in the phyllonite have Z asymmetry. Dextral shear bands (c'), and s-c fabrics have formed in the schistose matrix on the limbs of the folds (Figure 019.3b). Folds in the phyllonite have no axial-planar fabric aside from a locally developed crenulation cleavage, and their axes plot on a small circle in stereographic projection. This suggests that the folds have been refolded, perhaps by progressive deformation. One structure in particular appears to have developed by layer-parallel buckling and the formation of small folds which were later refolded into a larger Z fold during continuous shear (Figure 019.3c).

Layer-parallel breccias, and stringers of what have been interpreted to be pseudotachylite (Hugon 1984; Muir 1985b), also appear to have been associated with dextral shear. The breccias are composed of angular fragments, millimetres to centimetres in size, in a matrix which is either very fine grained, indurated, and probably consists of comminuted country rock, or is crystalline and consists of an apparently monomineralic, buff-weathering material. Layer-parallel breccias do not everywhere show a particular asymmetry, but they are commonly parallel

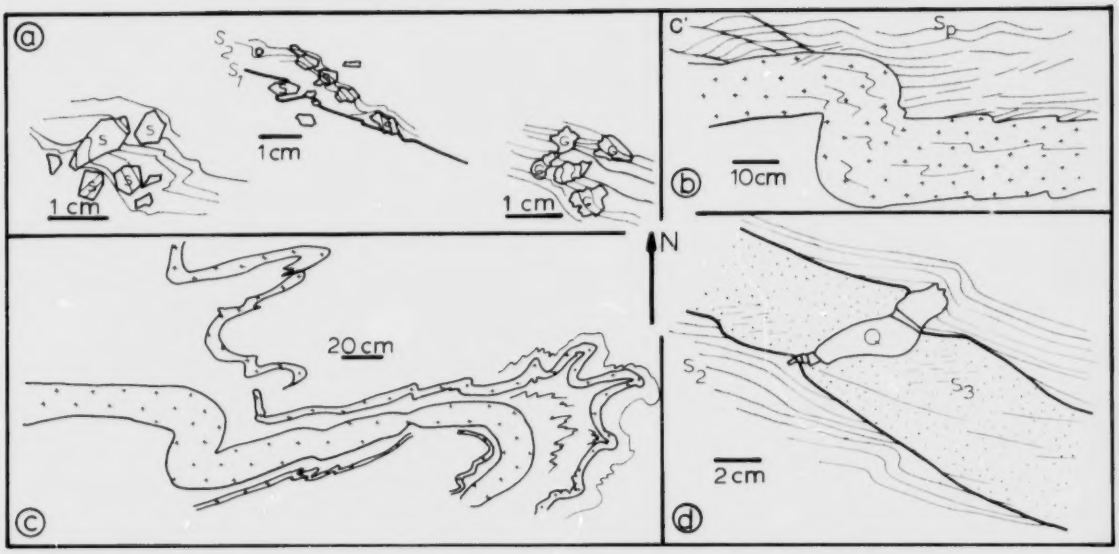


Figure 019.3. *Structures related to dextral shear. a) Porphyroblasts overprinting S_2 and rotated clockwise. The staurolites (S) appear to have overgrown S_2 under static conditions and been rotated during dextral shear. Location E, Figure 019.1a. The garnets (G) at the "Back 40's" outcrop (location D, Figure 019.1a) may have overgrown S_2 during dextral shear. b) Dextral (Z) fold of mafic dike with dextral shear bands (c') in the phyllonitic fabric (S_b) on fold limb. Highway 17, Hemlo Fault Zone northeast of Finger Lake. c) Folded felsic dikes in phyllonitic chlorite-actinolite-talc schist in the Hemlo Fault Zone west of the Page-Williams Mine on Highway 17. This structure may have formed by progressive dextral shear. d) Over-rotated, dextral tension gash (Q) producing F_3 fold in S_2 layering with incipient development of S_3 cleavage.*

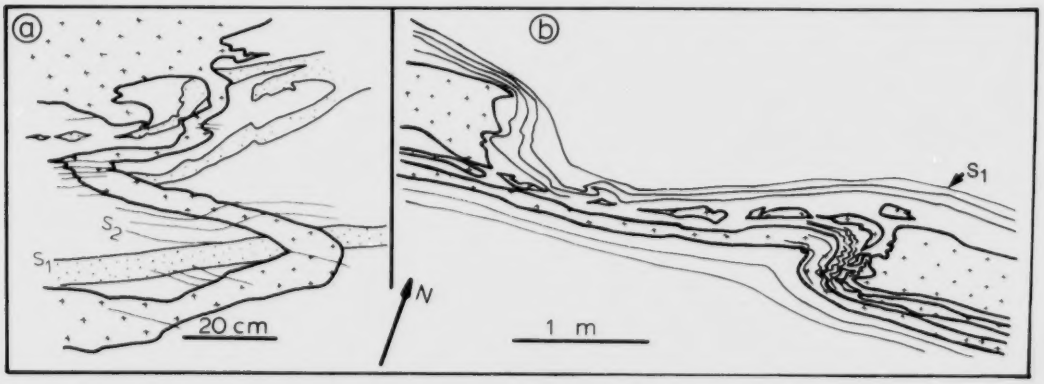


Figure 019.4. *a) Apophysis (crosses) of the Cedar Creek Stock (top of sketch) folded by F_2. Location F, Figure 019.1a. b) Feldspar-porphyry dike (crosses) which was pulled apart and now lies on the left-hand limbs of F_3 folds. Narrower dikes have been extended and folded by F_3. Highway 17 north of Finger Lake.*

to zones of layer-parallel, dextral displacement. Locally the matrix of the breccia is micaceous, and contains dextral shear bands and s-c fabrics (e.g. between the Golden Giant Mine compound and Cedar Creek).

On Highway 17 south of Moose Lake, a felsic dike is offset dextrally along a layer-parallel breccia cored by a pseudotachylite stringer. The breccia and stringer terminate in a dextral F_3-type fold, suggesting that some brittle faulting may have been contemporaneous with F_3 folding. In the same outcrop, a dextral F_3 fold is truncated by a pseudotachylite stringer, which therefore postdates F_3 folding. East of the Golden Giant Mine, stringers of pseudotachylite crosscut the matrix of a layer-parallel breccia. Brittle faulting, brecciation, and the formation of pseudotachylite stringers, are interpreted to have occurred during the late stages of dextral shear.

The lineations associated with dextral shear include dominantly subhorizontal slickensides and mineral fibres on S_1 and S_m surfaces, subhorizontal and east-plunging mineral lineations, and east-plunging F_3-fold axes and quartz rods. The S_1-parallel slickensides and mineral fibres are found throughout the area. In some rock types (e.g. gneissic amphibolite), elongate minerals are oriented parallel to the slickensides. Although lineations in the 1987 map area are generally subhorizontal, they tend to plunge toward the southeast near the Cedar Lake Pluton, and toward the northwest in the Hemlo Fault. In some outcrops, S_1-parallel slickensides plunge both southeast and northwest. On the road to the Golden Giant tailings pond, northwest of Cedar Creek, S_1-parallel quartz-feldspar veins were pulled apart into lozenge-shaped, "chocolate-block" boudins, with subhorizontal, S_1-parallel slickensides bisecting the acute angle.

The relationship between slickensides and quartz-rod orientation is consistent. Where slickensides are horizontal, quartz rods plunge to the east (as at the entrance to the David Bell Mine, location H, Figure 019.1a). Where slickensides plunge towards the northwest, quartz rods are subhorizontal. Mineral lineations mimic this relationship, as, for example, above the Barren Sulphide Zone, where the long axes of anthophyllite crystals plunge parallel to F_3 axes in fold closures and are subhorizontal on fold limbs.

Fourth-generation structures include kink bands of both Z and S asymmetry. Kink axes plunge steeply north and kink bands trend generally northwards, though conjugate sets and box kinks have been observed. Kink bands are locally associated with the layer-parallel breccias, as are small-scale, brittle faults oriented at high angles to layering; both are common in competent lithologies. The small-scale faults have millimetre- to centimetre-scale, dextral and sinistral offsets. Offsets die out along the length of the faults, which are typically less than a metre long. The faults locally crosscut layer-parallel breccias.

DISCUSSION

Hugon (1984) was the first to report dextral shear within the Hemlo area. Hugon (1984, 1986) concluded that the present geometry of the Hemlo Belt supracrustal rocks resulted from a single, progressive and protracted, dextral, deformation event. Although progressive deformation is probably responsible for some of the observed structures, it is perhaps more useful to consider separately the different generations in order to outline the geometry and deformation history of the Hemlo Belt. Diverse evidence points to differences in style, rate, and physicochemical conditions of deformation that prevailed during the development of the various generations of structures.

First-generation structures (F_1 folds and layer-parallel disrupted units) are confined to single horizons and appear to have formed during layer-parallel differential movement. Because no deformation structures prior to F_1 folds have been recognized, it might reasonably be assumed that layering was still subhorizontal when first-generation structures were formed. This in turn implies that deformation was a result of thrusting or low-angle, normal faulting. On the west half of the "Back 40's" outcrop (location D, Figure 019.1a), a first-generation, layer-parallel-disrupted horizon terminates along strike against an oblique surface which is folded by F_2 (Photo 019.2). If this surface is unfolded, the geometry of the structure is equivalent to that of a thrust or low-angle normal ramp.

The low-angle faulting discussed above was followed by F_2 folding and sufficient metasomatism to produce an axial-planar-differentiated layering. The L_2 intersection lineations associated with F_2 folds are presently subhorizontal to east-plunging near the Cedar Lake Pluton, and subhorizontal F_2 folds have been found (near location J, Figure 019.1a). The abrupt changes in the relative orientations of S_1 and S_2, and the overall paucity of obvious fold closures near the David Bell Mine and along the Noranda tailings road north of Cedar Creek, also suggest that F_2 might be shallow plunging in those areas. Near the Hemlo Fault along Highway 17, and on the Page-Williams Mine site, F_2folds plunge to the northwest. The orientation of F_2 folds on the south side of the Hemlo Fault is not known, nor is the orientation of F_2 folds to the north of the mineralized area of the Hemlo Belt. Further mapping should help clarify the overall geometry of F_2folding.

It is possible to speculate that the present variation in F_2 axes, from southeast-plunging near the Cedar Lake Pluton to northwest-plunging near the Hemlo Fault, may be related to F_2-synchronous, sinistral shear. Sinistral shear is indicated by the prevalence, near and within the Hemlo Fault zone, of S-shaped F_2 folds and of undeformed remnants of the S_2 cleavage oriented clockwise to S_m (Figure 019.2c) (i.e. S_2 and S_m have the relative orientations of a sinistral s-c fabric). S-shaped folds and remnant sinistral s-c fabrics can also be observed in the phyllonite within the Hemlo Fault. Sinistral shear associated with F_2 folding could also be invoked to explain the presence of the F_2 fold which is overprinted by an S_2-like, differentiated fabric (Figure 019.2d), indicating progressive ductile deformation. Sinistral shear associated with early movement on the Hemlo Fault is also suggested by the truncation of layering in the gneissic amphibolite unit, south of Highway 17, against feldspathic, mylonitic layering, north of the highway, within the Hemlo Fault (Figure 019.1a). The layering in the gneissic amphibolite is now oblique, in a clockwise sense, to the S_m fabric in the feldspathic mylonite: this is opposite to the sense that would be expected to result from drag on layering during dextral shear. Petrographic study of mylonitic textures should help to elucidate the stages of faulting and sense or senses of shear on the proto-Hemlo Fault.

F_2 folding was followed by the growth of porphyroblastic garnet and staurolite, and perhaps by growth of kyanite, sillimanite, and anthophyllite. Some garnet and staurolite can be seen with the naked eye to overgrow the S_2 cleavage (Figure 019.3a). F_3 folding and dextral shear followed porphyroblastesis, resulting in clockwise rotation of garnets and staurolites on both limbs of F_2 folds.

Dextral shear was penetrative across the portion of the belt studied. Zones of dextral shear within the Hemlo Fault contain dextral s-c fabrics in schistose layers, F_3 Z folds, and layer-parallel slickensides. The chlorite-actinolite-talc phyllonite along the Hemlo Fault, the micaceous garnet-staurolite-anthophyllite-sillimanite-schist above the Barren Sulphide Zone (location G, Figure 019.1a), and the Hemlo ore zones were the foci of the most intense, dextral shear.

The fact that layer-parallel slickensides, though dominantly horizontal, range in plunge between moderately to the southeast and moderately to the northwest, suggests a rotational component of shear, perhaps related to the curvature of the belt itself. Hugon (1984, 1986) concluded that dextral shear was a result of thrusting, with movement of the north block upwards and to the east. We found no evidence, however, that lithological layering was near horizontal at the time of dextral shear, and as dips now range from moderate to steep toward the north-northeast to northeast, it is assumed that dextral shearing was dominantly transcurrent, perhaps with a reverse, north-side-up component. The association of "chocolate-block" boudins with layer-parallel, subhorizontal slickensides and mineral lineations indicates a shortening component associated with the dextral shear.

The late stages of dextral shear produced layer-parallel breccias, pseudotachylites, and, finally, kink bands. Third- and fourth-generation structures were thus produced during one progressive deformation event involving brittle-ductile followed by brittle forms of rock failure.

RELATIONSHIPS BETWEEN DEFORMATION, METAMORPHISM, AND FELSIC INTRUSIVE ROCKS

The Cedar Lake Pluton (2687 Ga; Corfu and Muir 1986) and the Cedar Creek Stock have been affected by both F_2 and F_3 folding, and by dextral shear. At the western margin of the Cedar Lake Pluton on Highway 17, a large, micaceous xenolith or country-rock screen contains stringers of granitic material which are isoclinally folded, and these folds are refolded by F_3 Z-folds which pass into an S_3 crenulation in the xenolith. Away from the contact, along Highway 17, apophyses of a thick, feldspar-porphyritic granodiorite sheet (2698 Ga; Corfu and Muir 1986) have been folded into tight F_2 folds and overprinted by S_2. Along Highway 614, apophyses of the Cedar Lake Pluton within the metasedimentary country rock are also folded, and have an axial-planar cleavage. Along the southern margin of the Cedar Creek Stock (location F, Figure 019.1a), apophyses of the stock are tightly folded and the S_2 cleavage is axial-planar to the folds (Figure 019.4a).

Only one fabric has been recognized in either the Cedar Lake Pluton or the Cedar Creek Stock, and that fabric is a poorly to moderately well-developed preferred dimensional orientation of biotite and hornblende, and an alignment of the long dimensions of schistose xenoliths. At the western margin of the Cedar Lake Pluton, the fabric is roughly parallel to the margin. Both the fabric in the Cedar Creek Stock and S_1 in the country rocks are parallel to the margins of the stock (Figure 019.1b); however, towards the centre of these intrusions, where mapped, the fabric trends easterly.

On Highway 17, towards the middle of the Cedar Lake Pluton, and in the Golden Giant Mine backfill quarry, towards the centre of the Cedar Creek Stock, mafic dikes, striking at 050°, show evidence of dextral shear parallel to dike margins, and the fabric in the pluton crosses the dikes with a sigmoidal, right-lateral trace. Near the western margin of the Cedar Creek Stock, along the powerline north of the Golden Giant Mine, aplitic dikes in the pluton are thinned and rotated clockwise where they cross a country rock xenolith or screen. This indicates that dextral shear has occurred preferentially in the layer-silicate-rich xenolith. The aplite dikes are crosscut by a mafic dike of the type described above as being affected by dextral shear.

Porphyry dikes are abundant in the Hemlo Belt. They commonly contain a schistose fabric, and are locally quite sheared. In some, small-scale apophyses are drawn out into the S_2 cleavage. On a regional scale, porphyry dikes are parallel to the trace of F_2 axial planes and do not appear to be folded by F_2. The dikes are folded by F_3, or they form the limbs of F_3 folds in boudin necks (Figure 019.4b).

The dikes likely do not all belong to the same suite, but most appear to have been intruded during or after F_2 folding and before F_3 folding and dextral shear.

Metamorphic minerals such as garnet, staurolite, kyanite, sillimanite, and anthophyllite appear to be concentrated in zones well away from either the Cedar Lake Pluton, the Cedar Creek Stock, or the Pukaskwa Gneissic Complex (which lies to the south of the area shown in Figure 019.1a). There are very few visible porphyroblasts near the margins of these bodies, even though the country-rock lithologies near the first two bodies listed above appear to be ideal for the growth of garnet or staurolite. At least some F_2 folding and related deformation postdated intrusion of the granitic bodies but predated porphyroblastesis near the Hemlo deposits. The growth of garnet, staurolite, and other metamorphic minerals possibly resulted from metamorphism or alteration which occurred some time after granitoid intrusion.

Some garnets, which show dextral (clockwise) rotation, contain curved inclusion trails interpreted by Hugon (1986) to indicate synkinematic porphyroblast growth. Walford *et al.* (1986b) report garnets showing reverse manganese-iron-zonation profiles and elevated manganese concentrations (within and near the ore zone). They point out that this may represent some form of polymetamorphism. The above points suggest that while some garnets grew in static higher pressure and temperature conditions, others grew during dextral shear under retrograde metamorphism.

RELATIONSHIPS BETWEEN DEFORMATION AND MINERALIZATION

The most striking aspect of the Hemlo Au-Mo ore body is its elongate shape and plunge of approximately 45° towards the northwest (Harris 1986; Burke *et al.* 1986; Valliant and Bradbrook 1986; Walford *et al.* 1986b). This plunge is parallel to F_2-fold axes and

L_2 lineations which are contained in rocks near the up-dip projection of the mineralized zone, and within the Hemlo Fault. Though there is no evidence that the ore zone occupies the nose of a large-scale F_2 fold, the parallelism of the ore zone and the second generation lineations is not considered coincidental. F_2 folds appear to have a geometric, and possibly genetic, relationship to Au-Mo mineralization.

It has not yet been determined when mineralization began, but two possibilities are suggested:

1. Au-Mo mineralization occurred during F_2 folding and was related to fluids and processes involved in the development of the S_2cleavage
2. Au-Mo mineralization occurred after F_2 folding. and the mineralizing fluids used F_2 fold axes and/or the S_2 cleavage as conduits

The ore zone is deformed (Burke *et al.* 1986; Harris 1986; Hugon 1986; Kuhns *et al.* 1986; Walford *et al.* 1986b), although there is some disagreement among the above authors as to the timing of mineralization with respect to deformation and metamorphism. This disagreement may be resolved in part by the recognition of more than one deformation event. Third- and fourth-generation structures do overprint the ore body, and the main mineralized zone appears to be a zone of intense dextral shear, as is the Barren Sulphide Zone (location G, Figure 019.1a), and the Highway Zone (location A, Figure 019.1a). Other zones of intense dextral shear are not mineralized (eg: the phyllonite within the Hemlo Fault Zone). It appears, therefore, that the locations of dextral shear zones did not everywhere control the site of mineralization.

Mineralization also predated the intrusion of some dikes, which themselves predate at least some dextral shear. In the Golden Giant Mine, for example, Au-Mo mineralized rocks are crosscut by an unmineralized mafic dike (R. Kusins, geological co-ordinator, Hemlo Gold Inc., personal communication, 1987) which has undergone boudinage and then been shortened to form the limbs of an F_3 Z-fold similar to that shown in Figure 019.4b.

Walford *et al.* (1986b) and Muir (1986) relate Au-Mo mineralization to potassic feldspathization of the host rocks. Harris (1986) noted barian microcline associated with the mineralized zone, and suggested that the paragenetic origin of feldspar was related to fluids that hydrothermally altered the ore zone. On the "Heritage Outcrop" (location C, Figure 019.1a), feldspathized seams have been folded by F_2, but the S_2-differentiated layering appears to be defined, at least within the ore zone, by younger feldspathic seams. Near location B (Figure 019.1a), veinlike, altered seams (*see* Muir 1986) which pass into more massively altered rocks have the same relationship to the S_2 cleavage as do the feldspar-amphibole segregations shown in Figure 019.2b (i.e. clockwise from S_2 on the northwestern limb of a northwest-closing fold). At least some feldspathic alteration is very late, because sets of 2 to 10 mm thick feldspathic bands centred on north-northwest- to north-northeast-trending fractures crosscut all generations of structures in the Hemlo area. Various stages and/or types of feldspathic alteration, therefore, occurred over an extended period: this does not help us to pinpoint the timing of mineralization.

With respect to metamorphism, most authors agree that principal mineralization predated a final retrograde stage of metamorphism. Although it is not discussed in their papers, photomicrographs of ore zone rocks shown by Harris (1986), Kuhns (1986), Kuhns *et al.* (1986), and Walford *et al.* (1986) all show annealing textures. Burke *et al.* (1986) recognize two stages of metamorphism; the first stage at high pressures and moderate temperatures, the second at moderate pressures and temperatures. Their Figure 4c shows a bent kyanite crystal with its long axis at a high angle to the main foliation, and a sillimanite crystal parallel to the main fabric. Our field observations show that sillimanite is aligned in S_3. The metamorphism that resulted in the static overgrowth of staurolite on S_2, and possibly the development of kyanite, was probably responsible for the annealing of the ore zone host rocks. Petrographic work may help determine whether ore minerals were present at the time of annealing. Harris' (1986) descriptions suggest that this may be the case. He describes free gold as occupying grain boundaries between quartz, potassium-feldspar, and pyrite.

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Wawa Area

020. Geoscience Studies in the Wawa Region

R.P. Sage

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

For roughly ten years the Ontario Geological Survey has carried out a program of bedrock mapping in the Wawa area designed to stimulate exploration for base metals and gold and to provide a base for proper regional land use planning. The geological program involved three main disciplines, namely geological mapping, structural mapping and descriptions of mineral deposits. Geochemical, geophysical, detailed structural and detailed mineral deposit studies began in 1987 as part of an integrated geoscience program.

Since 1979, geological bedrock mapping of the central Michipicoten Greenstone Belt has been carried out by the Ontario Geological Survey covering a total of 15 townships (approximately 870 km^2) (Sage 1979, 1985). Adjoining areas, including Mishibishu Lake, Matchinameigus Lake, Mishewawa Lake and Molybdenite Lake were mapped by Bowen and Logothetis (1985), Bowen (1986), Downes (1978), Mandziuk (1980) and Massey (1982, 1983). During the Summer of 1987, Sage (this volume) mapped in the Goudreau-Lochalsh and Kabenung Lake areas and Reid and Reilly (this volume) completed work in the western portion of the Mishibishu Lake Greenstone Belt.

Bedrock mapping over the last ten years has resulted in major lithological-lithostratographical reinterpretations and a better understanding of the structural framework of the area. Three, possibly four, volcanic cycles have been outlined showing strongly bimodal composition. Carbonate alteration is widespread as are zones of chloritoid development. Gold-bearing quartz veins are associated with several zones of carbonate alteration.

Structural studies were begun in 1987 by Zaira Arias and focused on areas of known gold mineralization in the Goudreau-Lochalsh area. She concentrated her investigations on the Goudreau Lake and Cradle Lakes deformation zones and presents a summary report on her work in this volume.

K.B. Heather (this volume) studied in detail many of the gold deposits in the Goudreau-Lochalsh area and Mishibishu Lake area (Heather 1985, 1986) and has demonstrated clearly that gold, as in many other areas of the Superior Province in Ontario, is associated with zones of coincident deformation and hydrothermal alteration.

In addition to bedrock mapping by the Precambrian Geology Section in 1987, R.B. Barlow of the Geophysics-Geochemistry Section, supervised the completion of an electromagnetic and magnetic airborne survey of the Michipicoten Greenstone Belt. Also in 1987, a lake water and lake bottom sediment geochemical survey was carried out by J.A.C. Fortescue of the Geophysics-Geochemistry Section.

Several small areas of moderate to high mineral potential within the Michipicoten Greenstone Belt remain to be mapped in detail and several structural and mineral deposit studies are planned for the coming years. An airborne radar imaging survey will be flown over part of the greenstone belt in the Fall of 1987 or early Spring of 1988. This survey will help in a regional structural analysis that will possibly lead to a better definition of major deformation zones in the area and hopefully stimulate additional exploration for structurally controlled gold mineralization.

A small area southeast of Goudreau has been selected as a test site by geoscientists from several disciplines to investigate the practicality of integrating digitized geoscience data and to test the gathering of digitized field data. The data will be used to produce geological, structural, metallogenic, geophysical and geochemical maps of the test site.

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021. Geology of Goudreau-Lochalsh and Kabenung Lake areas, District of Algoma

R.P. Sage

Geologist, Ontario Geological Survey, Precambrian Geology Section, Toronto.

INTRODUCTION

Exploration activity in the Michipicoten area is presently intense. In Finan Township, Canamax Resources Incorporated is planning to bring its Kremzar Property into production in 1988 (The Northern Miner, May 11, 1987) and Muscocho Explorations Limited is installing a test mill on its Magino Property (The Northern Miner, July 13, 1987). At the east end of the Michipicoten Greenstone Belt, the Renabie Mine has produced gold intermittently since the 1930s and has reserves exceeding one million tons grading 0.25 ounces per ton (The Northern Miner, August 24, 1987).

Within the nearby Mishibishu Greenstone Belt, Muscocho Explorations Limited is meeting with success at its Magnacon Property (The Northern Miner, June 1, 1987; August 3, 1987).

The presence of intense exploration activity in the Wawa area provides a stimulation to geologically investigate those areas of the Michipicoten Greenstone Belt which previously have not received intense geological examination.

Field work in 1987 was completed in two widely separated areas in the Wawa region (Figure 021.1). Area I includes Jacobson, Finan, and Dunphy Townships in the Goudreau-Lochalsh area. Mapping began in Area I in 1985 and was completed in 1987, bringing to a close the original Wawa program initiated in 1979 to map the 12 townships that cover the core of the Michipicoten Greenstone Belt.

Area I is accessible by gravel road from Dubreuilville and by numerous logging and mining skid roads. That portion of Dunphy Township underlain by supracrustal rocks is accessible by a logging skid road or by traversing west of the Algoma Central Railway.

Area II is an extension of the original Wawa mapping program and includes the townships of Lalibert, Knicely, and Killins. These townships contain a number of mineral showings and are known for their lithologic diversity and structural complexity (Milne *et al.* 1972; Bennett and Thurston 1976).

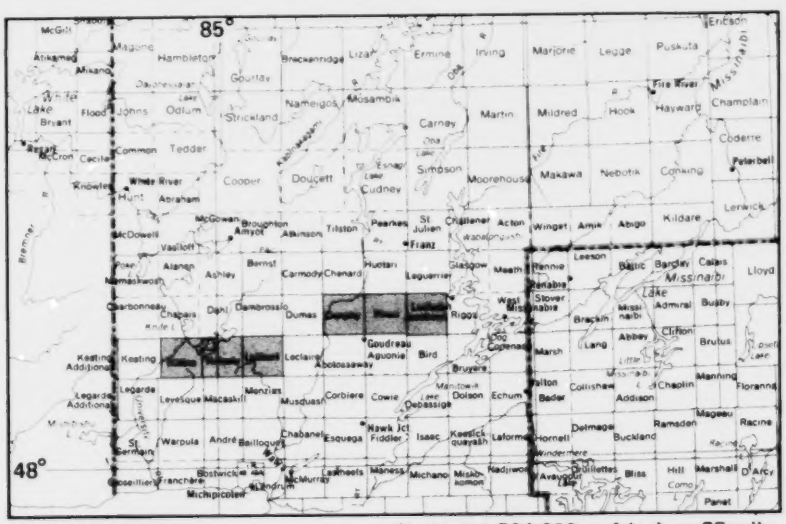
Area II is largely accessible by logging access roads and logging skid trails but locally a helicopter is required.

AREA I

MINERAL EXPLORATION

The area covered in Finan and Jacobson Township in 1987, lies north of the main area of gold and pyrite mineralization which is located between Goudreau and Lochalsh (Sage 1985). The area examined in 1987 has no past producers and only minor prospecting activity has occurred (Assessment Files Research Office, Ontario Geological Survey, Toronto). Evidence of prospecting activity in Dunphy Township is relatively scarce.

In early 1987, Cline Development Corporation completed extensive stripping and trenching on airborne geophysically indicated electromagnetic conductors in Jacobson and Finan Townships. Exploration was directed towards gold mineralization, however, the results of this work are unknown. Banded chert-magnetite iron formation was exposed in a number of the trenches.



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

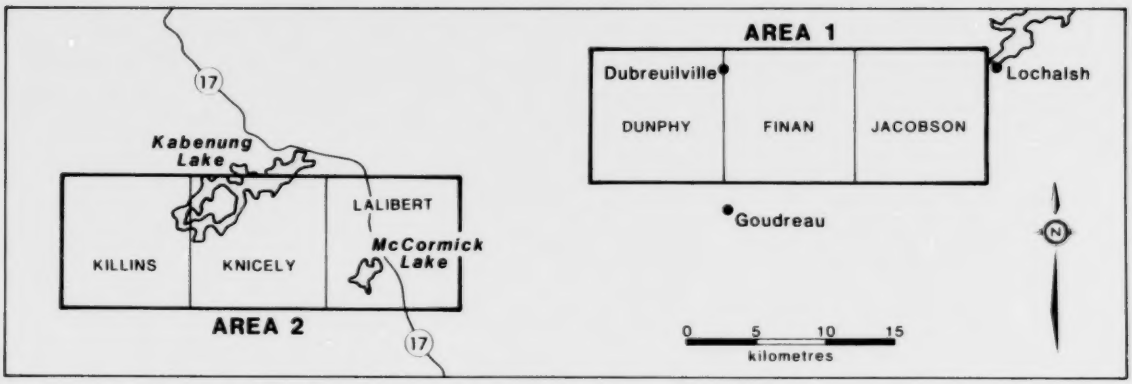


Figure 021.1. Sketch map illustrating relative positions of Areas I and II.

GEOLOGY

Finan and Jacobson Townships

Within Finan and Jacobson Townships, the northern limit of the Maskinonge Lake Granitic Stock was defined and it was determined that the nepheline syenite of the Herman Lake Syenite Complex partially envelopes the Maskinonge Lake Granitic Stock along its northern perimeter (Figure 021.2).

The metavolcanics examined in 1987 consist almost exclusively of massive and pillowed intermediate to mafic flows. The intermediate to mafic metavolcanics are separated from the external granites by a thick sequence of thinly to thickly bedded Dore-type wacke with minor conglomerate. Minor intrusions of fine to coarse metagabbro to metadiorite are present. Minor thin bedded, continuous units of iron formation occur at or close to the metasedimentary-metavolcanic contact. The poorly exposed external granites consist dominantly of granodiorite and on the basis of crosscutting relations the external granites are younger than the supracrustal rocks. The granodiorites locally contain blocks of older trondhjemite and quartz diorite. The supracrustal and intrusive rocks are cut by a northwest-trending set of diabase dikes which commonly occupy fault or shear zones.

Dunphy Township

In Dunphy Township, outcrop is abundant along the northern contact of the Michipicoten Greenstone Belt with the external granitoids. The geology of the township is dominated by the Troupe Lake granodiorite to quartz monzonite stock. This stock is distinctive since it contains potassium feldspar phenocrysts up to 3 cm in length. The stock is coarse grained, inequigranular and sharply crosscuts the supracrustal rocks. A thermal aureole of contact metamorphism 200 to 300 m wide encloses the stock.

Intermediate to mafic metavolcanics are the dominant lithology and they are separated from the external granitic rocks by a band of Dore-type metasediments approximately 1.0 km wide. The metasediments consist of thinly to thickly bedded wacke, siltstones, and conglomerate. The metasediments are the western extension of the metasediments found in Jacobson and Finan Townships.

Minor bands of thinly bedded chert-magnetite iron formation occur at or near the metavolcanic-metasediment contact. Numerous fine- to coarse-grained bodies of metagabbro or metadiorite cut the supracrustals.

All rock types are cut by a set of northwest-trending diabase dikes that commonly occupy faults or shear zones.

STRUCTURAL GEOLOGY

Finan and Jacobson Townships

In Jacobson and Finan Townships, based on pillow shape, the strata face consistently north. Primary sedimentary structures used to determine facing directions are rare and generally conflicting. Regionally the metasediments probably face north but locally tight folding may account for local facing reversals.

Dunphy Township

In Dunphy Township, the strata face north based on pillow shape. A stratigraphic south facing direction, indicated by Bruce (1940), southwest of the Troupe Lake stock was confirmed. The significance of this one south facing observation is uncertain but a minor fold likely exists. Stratigraphic facing data in the metasediments based on grain gradations is rare and conflicting but generally north.

ECONOMIC GEOLOGY AND RECOMMENDATIONS TO THE PROSPECTOR

Most prospecting activity in northern Jacobson and Finan Townships and in that portion of Dunphy Township underlain by supracrustal rocks has been directed toward outlining the extent of the iron formation. These iron formations are too narrow and low in iron content to be presently of economic interest. Visibly recognizable gold or base metal mineralization was not observed in any of the iron formations.

In Jacobson and Finan Township, trenching by Cline Development Corporation has exposed shear zones with carbonate alteration and silicification. These shears appear favourable for gold mineraliza-

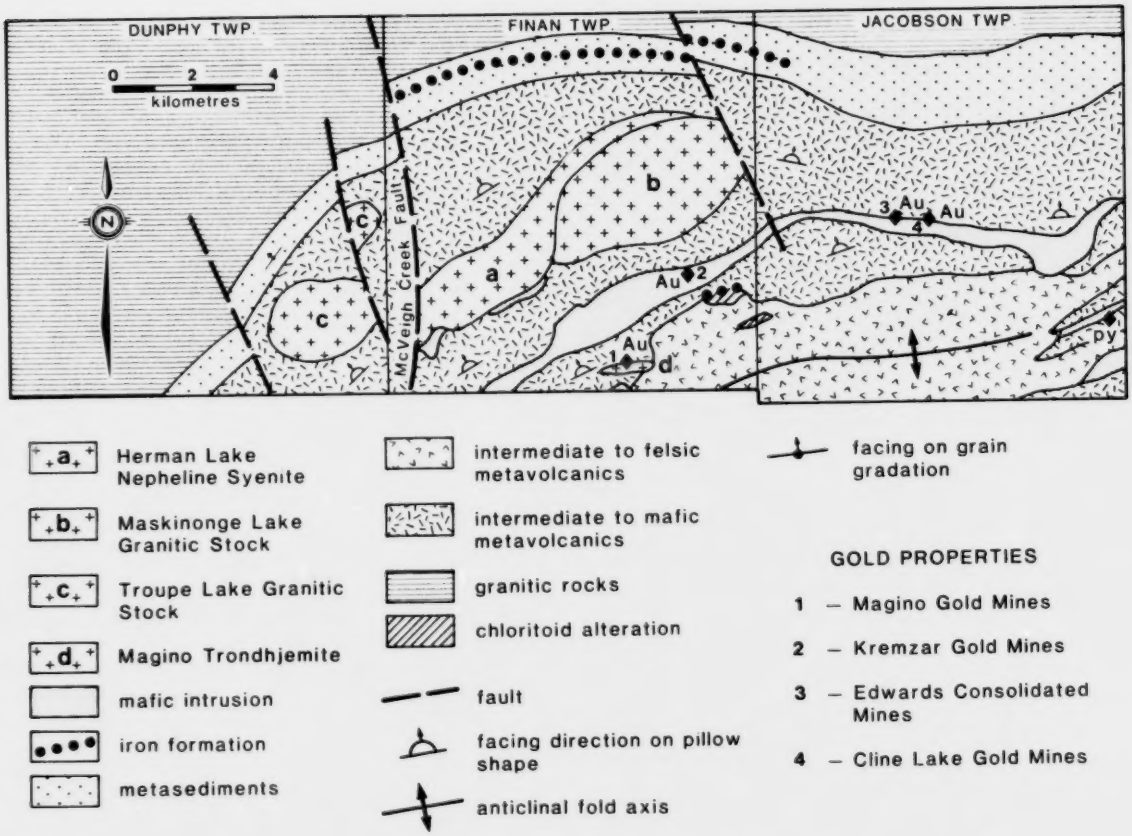


Figure 021.2. *Simplified sketch map of the geology of Dunphy, Finan and Jacobson Townships.*

tion. The extensive overburden cover in northern Finan and Jacobson Townships and in select areas of Dunphy Township likely cover many previously untested shear zones which may host gold mineralization.

Hornfelsed intermediate to mafic metavolcanics along the contact with the Troupe Lake granodiorite to quartz-monzonite stock commonly contain minor disseminated pyrite and pyrrhotite mineralization. Neither gold or base metal mineralization was recognized in the hornfelsed aureole.

AREA II

MINERAL EXPLORATION

Very little exploration work has been completed in Lalibert Township (formerly Township 30, Range 26). Most exploratory work has been completed on the Brant Lake Iron Range in the north-central part of the township. Mapping in 1987 did not include this iron range.

In 1975 Union Miniere Exploration and Mining Corporation Limited completed three diamond-drill holes in eastern Lalibert Township. This drilling was in search of base metals on airborne electromagnetic anomalies (Assessment Files Research Office, Ontario Geological Survey, Toronto).

GEOLOGY

Mapping within Lalibert Township is incomplete and gaps within the mapping prevent the presentation of a preliminary geological interpretation at this time. The reader should refer to previous published maps of the area (Milne *et al.* 1972) to relate to the following discussion of lithological distribution.

Lalibert Township east of Highway 17 consists of intermediate to mafic metavolcanics and metasediments. Previous interpretations (Milne *et al.* 1972) indicate a distribution of the metasediments which indicate a possible fold structure. These metasediments consist of thinly to thickly bedded wacke to subarkose, siltstone, mudstone and argillite. Mapping has indicated that the metasediments occur in a series of northwest-striking fault-bounded blocks which are distributed in a pattern not suggestive of a fold.

West of Highway 17, the supracrustal rocks consist of intermediate to mafic and intermediate to felsic metavolcanics.

The intermediate to felsic metavolcanics consist of quartz-feldspar crystal tuffs, tuffs, lapilli tuff, and

breccias. The breccias contain elongated, generally fine-grained, felsic clasts which locally exceed 1 m in length. Most clasts are, however, 0.3 m or less in length. The felsic clasts are set in a chlorite-rich matrix. The large fragment size of some breccias suggests proximity to a vent. The intermediate to felsic metavolcanics were interpreted previously as metasediments (Milne *et al.* 1972).

The supracrustal rocks are intruded by sill-like bodies of fine- to coarse-grained metagabbro and metadiorite.

The supracrustals and mafic intrusions are cut by a conjugate set of northeast- and northwest-striking diabase dikes. Uncommon east- and north-striking diabase dikes are also present.

Northwest of McCormick Lake, and extending to the eastern limits of Lalibert Township, are numerous small lamprophyric dikes containing rounded inclusions of actinolite up to 0.67 m in maximum dimension. A small syenite intrusion occurs on the north shore of McCormick Lake and in the area northwest of McCormick Lake a number of exposures of intensely brecciated rock were encountered. These brecciated outcrops are diatreme-like in appearance (Sage 1982). Contacts between the breccia and host rocks were not observed.

STRUCTURAL GEOLOGY

East of Highway 17, the fold suggested by the distribution of metasediments in previous interpretations (Milne *et al.* 1972) does not exist. The metasediments occur in a series of fault-bounded blocks and on the basis of grain gradation they face south. The axis for the Centre Anticline defined in adjoining LeClaire Township (Sage 1984) passes north of the metasediments and lies within pillowed and massive intermediate to mafic metavolcanics.

Southwest-facing intermediate to mafic metavolcanics along Highway 17 lie in sharp contact with intermediate to felsic metavolcanics a short distance west of the highway. In the southwest corner of the township, the intermediate to mafic metavolcanics display a consistent northeast-facing attitude based on pillow shape. The southwest-facing pillows along the highway and northeast-facing pillows in the southwest corner of the township indicate the presence of a syncline. The position of the axis of this syncline lies within the intermediate to felsic metavolcanics but the lack of facing data within this lithologic package prevents an accurate placement of the fold axis.

ECONOMIC GEOLOGY AND RECOMMENDATIONS TO THE PROSPECTOR

The presence of intermediate to felsic metavolcanics rather than metasediments in the western portion of Lalibert Township suggests a potential for base metal mineralization. Shear zones with associated carbonate and silica alteration were not observed and thus the gold potential is probably not as great as within other areas of the belt.

The area warrants additional prospecting for base metals. The area is structurally complex and shear zones are present. These shears should be routinely examined to locate possible areas of carbonate and silica alteration which could indicate the presence of gold mineralization.

ACKNOWLEDGMENTS

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022. Mishibishu Lake Area, Districts of Algoma and Thunder Bay

R.G. Reid[1] **and B.A. Reilly**[2]

[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Geological Assistant, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

This report summarizes the observations and interpretations made with regard to stratigraphy and structure of the Mishibishu Lake Greenstone Belt during the third season of a detailed (1:15 840 scale) mapping program. The area is centred approximately 40 km west of Wawa and is accessible by float-equipped aircraft to Mishibishu Lake, Mishi Lake, and Katzenbach Lake. Several smaller lakes located in the western parts of the map area are also accessible by float plane. A mine access road now exists, ending at Muscocho Exploration Limited's Magnacon mine site, approximately 2 km north of the western end of Mishibishu Lake. This 50 km access road originates from Highway 17, approximately 50 km north of Wawa. Topographic relief within the map area and lack of road or water access requires that helicopter support be utilized for transportation within most of the Mishibishu Lake Belt.

Approximately one-half of the 1987 field season was spent completing 1:15 840 scale mapping of the western part of the Mishibishu Greenstone Belt in the Homer Township area. This area covers about 175 km^2 and completes the total map area (1985 to present) which is bounded by Latitudes 47°54'30"N to 48°10'00"N and Longitudes 85°00'00"W to 86°00'00"W. The remainder of the field season was used to re-examine geologically complex areas and to address specific geological problems identified by earlier mapping (Bowen and Logothetis 1985; Bowen 1986; Heather 1985, 1986). The 1987 field season enabled the authors to make some preliminary interpretations of the area as a whole, which encompasses approximately 1 410 km^2.

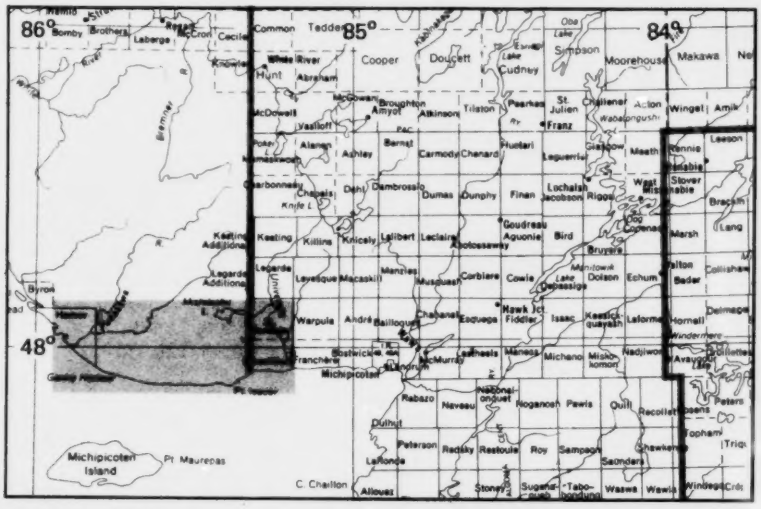
A strong emphasis was placed on structural data collection in an attempt to unravel the tectonic history of the belt; specifically the identification and documentation of deformation zones. Re-evaluation of previously mapped areas has resulted in the revision, in some cases only minor, of many of published Preliminary Maps of the area (Bowen *et al.* 1986a, 1986b, 1986c, 1986d, 1986e).

Current information on mineral occurrences was obtained from the Assessment Files, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Wawa, and the Assessment Files Research Office (AFRO), Ontario Geological Survey, Toronto.

MINERAL EXPLORATION

Past exploration activity in the Mishibishu Lake Belt has been summarized by Bowen and Logothetis (1985); Heather (1985); Bowen *et al.* (1986a, 1986b, 1986c, 1986d, 1986e); Bowen (1986); Heather (1986).

The Mishibishu Lake Greenstone Belt is the focus of much exploration activity this year. With the opening of an all-weather road into the Magnacon mine site, a great deal of heavy equipment has been transported into the immediate area of the mine site. The mine is a joint venture of Flanagan McAdam Resources Incorporated (50 percent), Muscocho Explorations Limited (25 percent), and Windarra Minerals Limited (25 percent). The Magnacon Project is



LOCATION MAP **Scale : 1:1 548 000 or 1 inch to 25 miles**

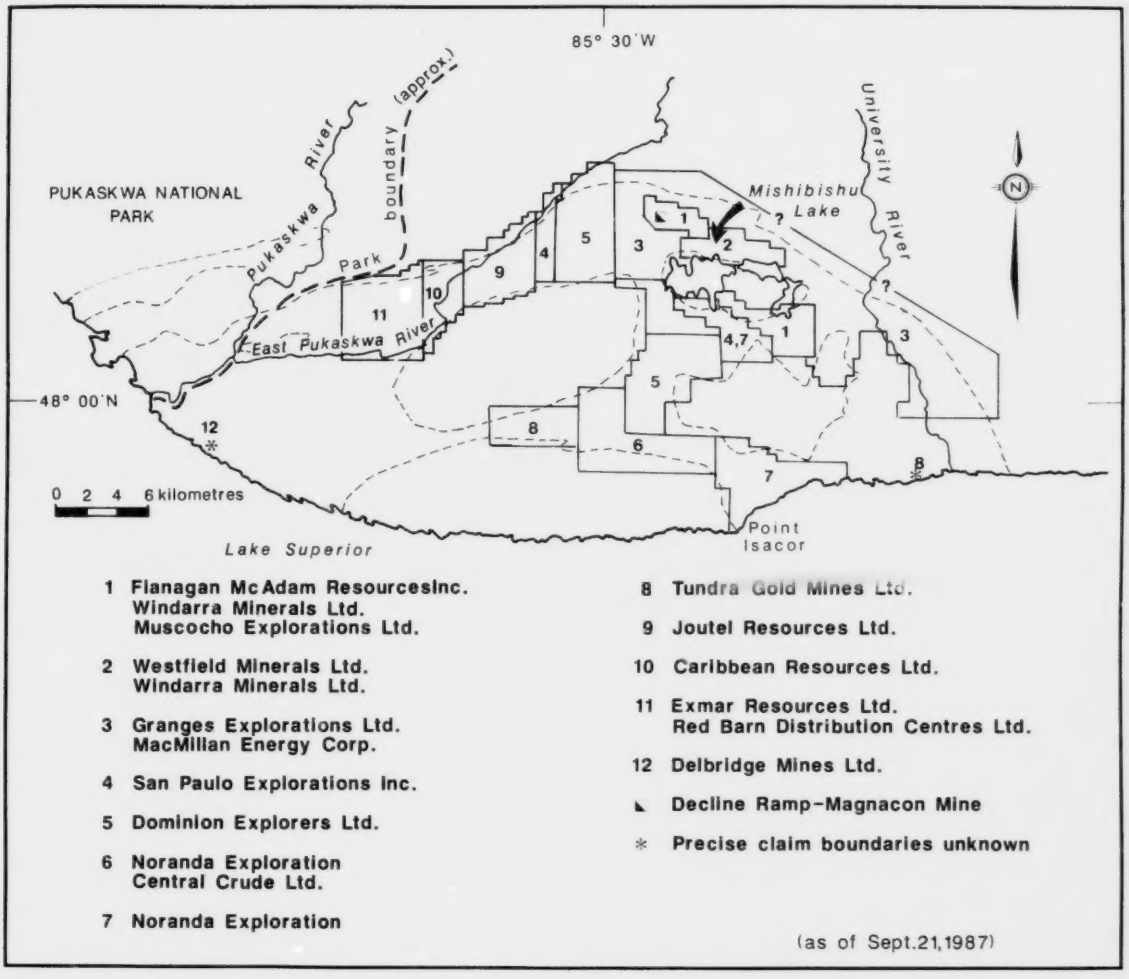


Figure 022.1. *Properties Location Sketch 1987.*

currently being developed on three separate mining levels, with encouraging results. Previous diamond-drill estimated ore reserves were 700 000 tons averaging 0.16 ounce gold per ton, and underground development is showing an estimated 30 percent increase in ore grade extracted (The Northern Miner, 1987a). A production decision for the mine is forthcoming.

Flanagan McAdam Resources Incorporated was also active on the Mishibishu Lake and Katzenbach Lake joint venture properties (Figure 022. 1). Linecutting and geological mapping of the properties is near completion, and surface diamond drilling is expected to commence shortly. Airborne geophysics was completed over these, and many other properties in the area, by Dighem Surveys and Processing Incorporated.

Airborne geophysics was completed in much of the Mishibishu and Wawa area for the Geophysics and Geochemistry Section of the Ontario Geological Survey. Results of this program will be released at a future date.

Granges Explorations Limited was very active again this year on their Mishibishu Lake property, which is under option from MacMillan Energy Corporation. The eastern portion of the property was surface mapped and prospected, and numerous exploratory diamond-drill holes were completed. Additional diamond drilling was also completed on the western portion of the property. Numerous ore grade intersections have been reported, but exact locations have not yet been released. A mineralized zone has been defined as having a minimum strike length of 275 m and open in all three directions. Drill core assays of 0.328 ounce gold per ton over 18 feet (5.48 m), and 0.16 ounce gold per ton over 22 feet (6.70 m) on the same zone have been reported (The Northern Miner 1987b).

Noranda Exploration Company Limited conducted surface mapping and prospecting on both their Central Crude Limited option and the Point Isacor prop-

erty. Some surface stripping and trenching has been completed, but accurate locations of work is not known. Noranda Exploration Company Limited has also recently completed an option agreement for the eastern property of San Paulo Explorations Incorporated (The Northern Miner 1987c).

Tundra Gold Mines Limited conducted a program of soil geochemical sampling, surface mapping, and prospecting on their University River and the western Maple Lake claim groups.

Dominion Explorers Limited are the current holders of the 'Scuzzy Little Lake' property, on which a diamond drilling program and detailed surface mapping was initiated in early September to better define zones of anomalous mineralization intersected during a 1986 diamond-drill program.

Numerous junior mining companies (Figure 022.1) currently hold properties along the East Pukaskwa River. Soil geochemical sampling, ground geophysics, and geological mapping is being performed on many of the claim blocks.

Delbridge Mines Limited carried out ground investigations which included stripping and trenching of their property; the located along the shore of Lake Superior. The property contains a previously recorded copper, silver, gold occurrence near Chimney Point in Homer Township.

GENERAL GEOLOGY

Detailed 1:15 840 scale geological mapping of the western portion of the Mishibishu Lake Greenstone Belt has markedly altered the reconnaissance mapping reported by Bennett and Thurston (1977). A previously unmapped intrusive rock type (quartz-feldspar porphyry), possibly related to a volcanic centre has been delineated in three adjacent areas, and a major regional folding episode has been more accurately documented.

The Archean supracrustal rocks of the region compose about 60 percent of the Mishibishu Lake area, and approximately 75 percent of the western portion of the belt, including the Bonamie Cove Enclave (Figures 022.2 and 022.3). The metavolcanics encountered in and around Homer Township are dominated by a series of intermediate metavolcanics consisting of massive flows, plagioclase porphyritic flows and crystal tuffs, and coarse pyroclastic debris flows. Relatively small lenses and zones of massive and pillowed mafic metavolcanic flows have been mapped. Massive, amphibolitized mafic metavolcanic flows dominate the Bonamie Cove Enclave.

Felsic metavolcanics in the western portion of the map area are almost non-existent, with only a few units located during the field season. These units are generally narrow, less than 5 m thick, and are very fine grained. These rocks are possibly tuffaceous rocks with minor phenocrysts of plagioclase and/or quartz. Field relationships indicate an extrusive origin; however, the units may represent hypabyssal sills.

Chemical metasediments consist of thin lenses of magnetite-bearing chert-wacke beds having a limited strike-length, and minor sulphide facies ironstones within some of the thicker magnetite-bearing units. The chemical metasediments are found as thin beds 1 to 10 m thick and show cyclic development with up to 4 periods of deposition, separated by intermediate and/or mafic metavolcanic units 10 to 25 m thick. The cyclicity of the ironstone units does not appear to be due to tectonic origin, as each individual unit has a characteristic mineralogy and variable thickness.

Clastic metasediments in the western portion of the Mishibishu Lake Belt form a relatively continuous band 1 to 2 km wide across the northern part of the area. They consist of polymictic clast-supported conglomerates, oligomictic quartz granule conglomerates, massive wackes, and minor laminated mudstones. Metasediments within the Bonamie Cove Enclave show migmatitic textures within polymictic conglomerates and massive wackes. Preliminary assessment of all data pertaining to the metasediments in the Mishibishu Lake Belt (Bowen 1986; Pomainville 1987) indicates the western portion represents a more proximal facies of turbidite deposition relative to the eastern, more distal submarine fan type deposits caused by rapid uplift and erosion of the area.

Coarse-grained gabbroic and dioritic rocks occur within the mafic and intermediate metavolcanic units. Intrusive contact relationships were observed in many localities. The rocks may be thick mafic flows or synvolcanic sills. The Loon Lake gabbro does exhibit a well-exposed brecciated contact with an intermediate crystal tuff to the north. Fragments average 3 to 10 cm in diameter, and are confined to a zone about 3 m wide near the intrusive contact. The gabbro also contains a sulphidic (pyrite) horizon about 1 m thick, parallel to the contact, and the regional foliation, and may be of magmatic origin.

Three melanocratic quartz-feldspar porphyry bodies were encountered in Homer Township. These bodies are composed of equigranular quartz and plagioclase phenocrysts (2 to 8 mm) in a strongly foliated chloritic to amphibolitic matrix. The main body, centred south of the mouth of the Pukaskwa River, shows an interfingering contact some distance into the metavolcanic sequence. Contacts, where exposed, are generally highly brecciated zones 1 to 20 m wide. One quartz-feldspar porphyry outcrop shows angular fragments of ironstone up to 4 m in diameter, intermixed with smaller fragments of mafic and intermediate metavolcanics, and all are cut by sulphide veinlets of pyrite with minor chalcopyrite and pyrrhotite. The other large porphyry body, north of the Pukaskwa River, is similar in composition, and probably of similar origin. Contact relationships of this body were not observed due to thick overburden in the area. The main porphyry body may represent part of a large domal structure, capping a paleovolcano which may have produced the southern metavolcanic stratigraphy of the Mishibishu Lake Belt.

The Northern Batholithic Complex in the western portion of the Mishibishu Lake Belt area was investigated in some detail. The area is composed of numerous complex bodies of foliated to gneissic biotite tonalite-quartz diorite, foliated to gneissic hornblende and biotite-hornblende diorite-tonalite which occurs as inclusions within massive to foliated biotite

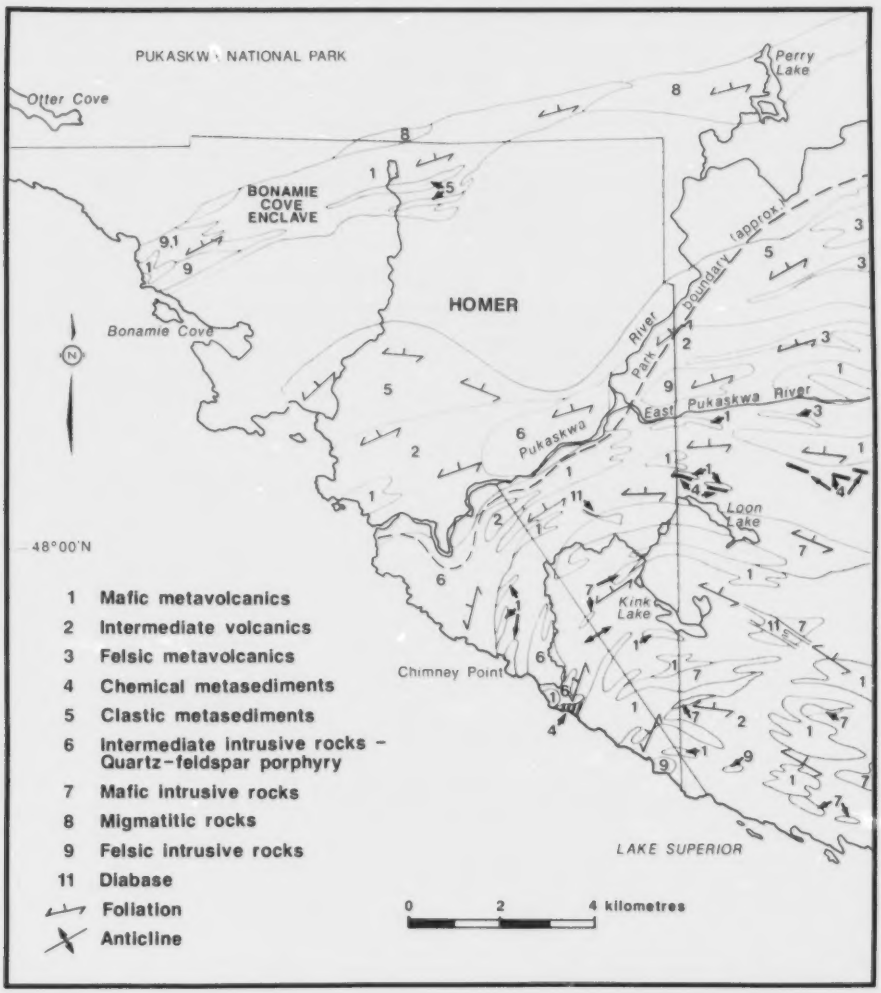


Figure 022.2. *Detailed Geology of the Homer Township Area.*

tonalite and quartz diorite, and hornblende-pyroxene granite. This is consistent with the findings stated for the eastern portion of the Northern Batholithic Complex by Bowen (1986).

The internal intrusive bodies were investigated briefly in 1987 for compositional variations within the plutons, and contact relationships with the supracrustals. These bodies include the Central Pluton, the Mishibishu Lake Stock, the Bowman Lake Batholith; the Southern Batholith is also possibly an internal body.

The Central Pluton is composed of a series of intrusive phases of similar composition. A detailed mineralogical study of this body is in progress. A metamorphic aureole of 10 to 100 m encircles the body.

The Mishibishu Lake Stock has very sharp intrusive contacts, has little or no associated contact metamorphic aureole and appears to have little to no structural influence on the surrounding supracrustal rocks.

The Bowman Lake Batholith has been investigated in previous years (Bowen and Logothetis 1985; Bowen 1986), and little time was spent reexamining it. This intrusive body was highly deformed and faulted after emplacement, and the majority of primary intrusive effects imposed on the surrounding rocks have been destroyed.

A number of small granitic intrusive bodies have been encountered within the western portion of the Mishibishu Lake Belt. These are similar to the small granitoid bodies elsewhere in the map area.

A very large number of diabase dikes cross-cut all the above rock types in the southwestern portion of the map area. All trend in a general northwest-southeast direction and vary in width from a few metres up to 100 m. The majority of these are probably of Keeweenawan age and related to mafic volcanism at that time. There is a definite shallowing

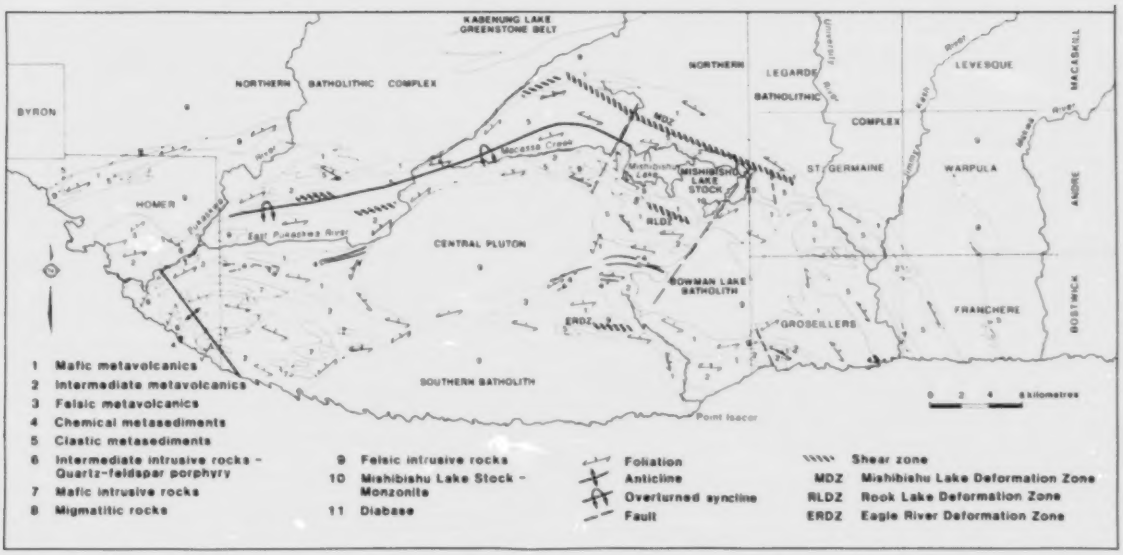


Figure 022.3. *General Geology of the Mishibishu Lake Greenstone Belt (modified after Bowen et al. 1986a,b,c,d,e).*

trend in the dip of the diabase dikes as one approaches Lake Superior, from steeply north-dipping in the north to a few tens of degrees north along the lakeshore. This dike swarm represents one of the three dominant sets of diabase dikes mapped previously in the Mishibishu Lake Belt (Bowen 1986). The other two sets were not observed in the western portion of the belt.

A few small Proterozoic mafic diatremes have been reported within the Mishibishu Lake Belt (Bowen 1986), and a small alkalic-syenite intrusion was encountered near the shore of Lake Superior, east of Point Isacor. Further work is required to fully define the composition of this body. A large number of flat-lying amygdaloidal basalt flows of Keeweenawan age are preserved along the shore of Lake Superior. A small felsic dike, suspected to be a Keeweenawan felsite, was found near the mouth of the Pukaskwa River.

Regional metamorphism within the western portion of the Mishibishu Lake Belt is generally of greenschist facies rank. Amphibolite grade metamorphism exists proximal to the intrusive bodies, in a contact metamorphic aureole varying in width from 300 to 600 m. Upper amphibolite grade is present in the Bonamie Cove Enclave.

Pleistocene deposits within the map area are generally ground moraine tills and clays of varying thickness up to several tens of metres. Beach sand deposits up to 100 m thick can be found near the shore of Lake Superior, notably near the mouth of the Pukaskwa River.

STRUCTURAL GEOLOGY

The predominant structural feature in the western portion of the belt is a major fold in the Kink Lake area (Figure 022.2). This fold, referred to as the Kink Lake Anticline, was first identified by Bennett and Thurston (1977) and correctly interpreted as an anticline based on the strike of the foliation in the supracrustals and top determinations from pillow shape. Detailed mapping this year has modified the geometry of this structure:

1. Foliation trajectories demonstrate that the fold is an open structure with a northwest-striking axial plane. The orientation of ironstone units, which are more prevalent in the northern limb, confirms that the foliation is parallel or at a low angle to bedding.
2. Foliations dipping steeply to the north on the northern limb become shallower toward the west-closing crest of the fold and eventually dip to the south on the southern limb which extends under Lake Superior. This geometry defines an antiform.
3. The Kink Lake Anticline plunges shallowly to the northwest.

Repetition of supracrustal stratigraphy indicates folding north of the Kink Lake Anticline; however, reliable top indicators were not found. This folding may be correlative with a broad arcuate, convex to the north, syncline mapped by Bowen (1986) which roughly bisects the exposed greenstone belt.

Regional folding of the supracrustals may be related to or concomitant with emplacement of foliated to gneissic granitoids of the Northern Batholithic Complex. Locally, along the granitoid-supracrustal interface, a strong downdip stretching lineation within highly strained rocks defines a contact strain aureole several hundred metres in width.

In the western portion of the belt, a weak to moderate east-trending penetrative foliation with a lesser developed, generally northward-plunging min-

eral lineation is associated with this regional phase of deformation.

Regional foliation and lineation patterns within the supracrustals are deflected around felsic plutonic bodies emplaced internal to the belt producing envelopes of contact strain (Figure 022.3). These internal granitoids vary in structure from massive to foliated. Both pure and simple components of shear are present within the aureoles which are generally sharply defined.

Strata-parallel, east-trending deformation zones were mapped north of the East Pukaskwa River. The loci of the zones are concentrated along lithological contacts and exposed widths measure up to 100 m. Brittle-ductile shear zones enclosing less deformed protoliths constitute the deformation zones. Macroscopic ductile structures include an intense penetrative fabric, strong stretching lineations, asymmetric folds, shear bands, boudinaged and rotated quartz veins, all indicative of simple shear. Later more brittle kink bands and crenulations are probably related to the same shearing event. Downdip stretching lineations plunge to the east in some zones and to the west in others. Kinematic indicators define both zones of normal and zones of reverse sense of shear displacement. The intensity of deformation and associated alteration varies in the deformation zones and they may be correlative with the Mishibishu Deformation Zone and Rook Lake Deformation Zone documented by Heather (1985), Bowen and Logothetis (1985) and Bowen (1986). A detailed microstructural, kinematic and alteration study documenting deformation zones throughout the belt is in progress.

Prominent airphoto lineaments, typically trending northwest and northeast, such as Macassa Creek and Katzenbach Lake "Faults", represent late brittle faults. These faults may occupy early ductile zones and locally are healed by diabase dikes (Heather 1985). Cross-structures of this orientation were not found in the western portion of the belt; however, regional lineaments such as the East Pukaskwa River exhibit similar topographic depressions and may be related to the same event.

Detailed mapping in the western portion of the belt completes mapping of the Mishibishu Lake Belt, thus permitting construction of a preliminary outline of the tectonic history which is not unlike other greenstone belts of the Superior Province (Stott 1985). Five main phases of deformation are recognized:

1. Regional compression producing major folds (e.g. Kink Lake Anticline) and a penetrative foliation. This event may be related to or concomitant with emplacement of the Northern Batholithic Complex external to the greenstone belt.
2. Emplacement of late, felsic plutonic bodies (e.g. Central Pluton, Bowman Lake Batholith, Mishibishu Lake Stock, and possibly the Southern Batholith) internal to the greenstone belt.
3. Regional oblique compression, with possible thrusting, producing strata-parallel deformation zones (e.g. Mishibishu Deformation Zone and Rook Lake Deformation Zone). The emplacement of some of the internal granitic rocks of phase 2, especially the Mishibishu Lake Stock, may be concomitant with or post date this event.
4. Regional fracturing and brittle displacement producing late brittle faults, typically cross-structures, which are manifested as lineaments (e.g. Macassa Creek, Katzenbach Lake and East Pukaskwa River). These faults may be related to the formation of the more ductile deformation zones of phase 3.
5. Emplacement of late diabase dike swarms in an extensional regime. Brittle faults of phase 4 may be related to or concomitant with this event.

ECONOMIC GEOLOGY

The Mishibishu Lake Greenstone Belt has been explored extensively for base metals in the past. Reference should be made to Heather (1986) for descriptions of many of these occurrences previously recorded, as well as full descriptions of many of the gold occurrences and properties currently being assessed by the exploration industry.

To date, gold occurrences within the Mishibishu Lake Belt are associated with deformation zones composed of brittle-ductile shear zones exhibiting varying degrees of hydrothermal alteration. Brittle cross-structures within the Mishibishu Deformation Zone are generally quartz filled and may have aided in the concentration of mineralization. Gold mineralization is typically associated with minor arsenopyrite and other base-metal sulphides.

The main deformation zones of the Mishibishu Lake Belt as defined by Heather (1986), notably the Mishibishu Deformation Zone (MDZ), the Rook Lake Deformation Zone (RLDZ) and the Eagle River Deformation Zone (ERDZ), have been found to have greater strike-length than was previously recorded. The RLDZ does not exhibit the degree of alteration and deformation observed in the MDZ. Detailed studies of the alteration patterns and the structural geology of the RLDZ are in progress.

Other isolated zones of deformation and alteration have been identified. Previously undocumented zones were delineated north of East Pukaskwa River. Minor alteration and base-metal mineralization within these zones was noted. These may be correlative with the MDZ and RLDZ. Detailed (property scale) investigation of this area is required to fully describe the geological setting of these zones.

Thick, laterally extensive gossan zones northeast of Katzenbach Lake have been identified (W. Bates, Granges Explorations Limited, personal communication, 1987). These zones are composed of approximately 50% strongly lineated quartz, 25% pyrite and 25% pyrrhotite. The origin of these zones is ambiguous as to whether they are primary massive sulphide deposits or secondary iron-rich hydrothermal deposits. Similar zones may exist elsewhere in the belt and should be investigated for economic potential.

The Loon Lake gabbro hosts a narrow (1 m) sulphidic (pyrite) horizon subparallel to its intrusive contact. The economic significance of the zone is not presently known. There is an abundance of gabbroic

and dioritic bodies in the western portion of the belt, and further investigation of all is warranted.

Narrow zones of silicification (2 to 5 m) have been recognized in the southwestern portion of the Mishibishu Lake Belt, along the shore of Lake Superior. They are hosted within the mafic and intermediate metavolcanics , and are usually situated near Proterozoic zones of brecciation with calcite alteration. Minor sulphide (pyrite, chalcopyrite) mineralization is associated with these zones.

The quartz-feldspar porphyry intrusions located in Homer Township may be related to a volcanic centre. If so, the possibility of massive sulphide and related mineralization may exist (Easton and Johns 1986), and warrants detailed investigation. The thick overburden of the area will hamper exploration, and the boundary of Pukaskwa National Park restricts the area that is open for exploration.

The highly strained rocks located within contact metamorphic and strain aureoles hold potential for mineralization, and have not been fully assessed during this survey. Further work should be completed in these areas.

The majority of the mineral rights within the supracrustal rocks of the Mishibishu Lake Greenstone Belt are currently held by companies or individuals. Potential hosts for mineralization include brittle-ductile shear zones, alteration zones (chlorite-calcite-ankerite-sericite (Heather 1986)), zones of silicification, zones of intense quartz veining, and possibly synvolcanic massive sulphides. These are all favourable exploration targets, and require systematic detailed investigation.

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023. Regional Structural Geology Related to Gold Mineralization in the Goudreau–Lochalsh Area, District of Algoma

Z.G. Arias[1] and K.B. Heather[2]

[1]Geological Assistant, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The 1987 field area, located about 40 km northeast of Wawa, includes portions of the townships of Finan, Aguonie, Jacobson, Bird, and Abotossaway, District of Algoma. The 250 km^2 area is bounded by Latitudes 48°12′N and 48°23′N and Longitudes 84°16′W and 84°30′W. Access from Wawa is provided by Highway 17 to 519, which leads to a network of mining and logging roads within the Goudreau-Lochalsh area.

The purpose of this project is to establish regional structural relationships to gold mineralization. The scale of the observations were at 1:15 840. The study complements detailed work (Heather and Arias, Article 024, this volume) which illustrates similar structural relationships observed at property and outcrop scales.

MINERAL EXPLORATION

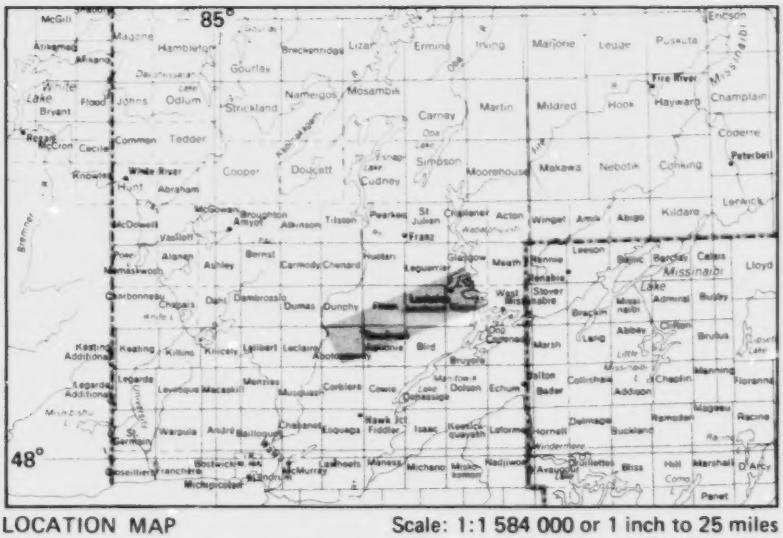
An account of past mineral exploration has been presented by Sage (1985). Heather and Arias (Article 024, this volume) discuss mineral exploration and activities during the 1987 field season.

GENERAL GEOLOGY

The geology of the area has been mapped by Sage (1983, 1984, 1985, and Article 021, this volume) (Figure 023.1) at a scale of 1:15 840 and is briefly summarized here.

A large felsic to intermediate metavolcanic pile consisting of coarse and fine pyroclastics, occurs in the central part of the study area. North of the felsic to intermediate pile are pillowed, massive, and schistose intermediate to mafic metavolcanics with minor intercalations of mafic pyroclastics. A unit of ironstone occurs along the contact between the felsic to intermediate and intermediate to mafic rocks. Medium- to coarse-grained quartz dioritic to gabbroic rocks appear to be roughly concordant to stratigraphy and occur within both the mafic and the felsic metavolcanics. The majority of these rocks are intrusive. Along the northern margin of the supracrustal sequence, thin bedded wackes and siltstones separate the intermediate to mafic metavolcanics from the external granitoids (Sage 1985).

Several internal felsic intrusive bodies occur within the area: a) the Gutcher Lake Stock of trondhjemite composition (Studemeister 1982; Sage 1985), located in west-central Abotossaway Township; b) the Herman Lake Nepheline Syenite Complex (Sage 1983, 1984), located in west-central Finan Township; c) the Maskinonge Lake Stock of granite (locally quartz deficient) to amphibole syenite composition



LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

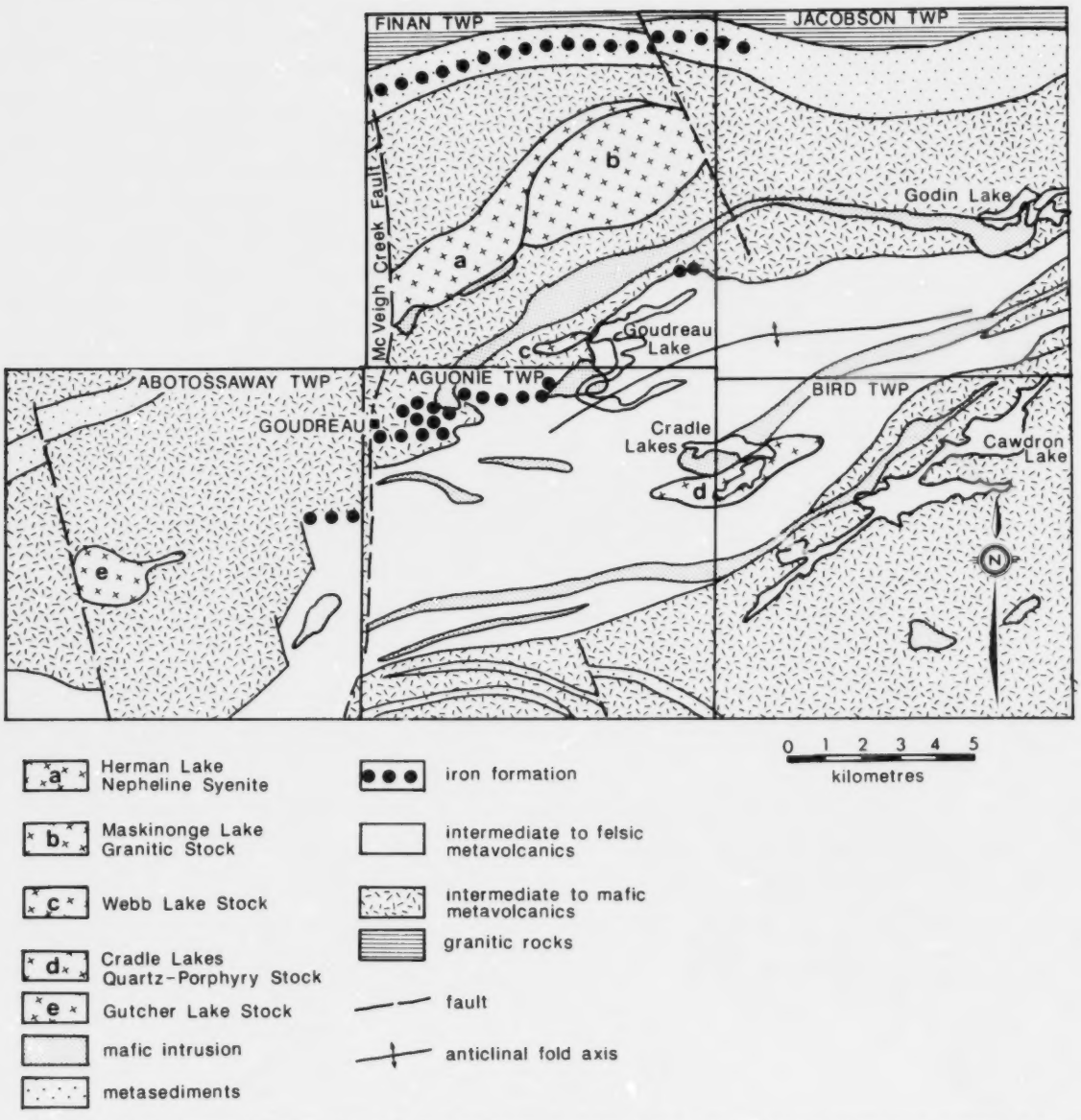


Figure 023.1. *General geology map of the Goudreau-Lochalsh area (after Sage 1985, and Article 021, this volume).*

(Sage 1983), located immediately east of, and intrusive into, the Herman Lake Complex; d) the Webb Lake Stock of trondhjemite (Sage 1985) or granodiorite (S. Markell, Geologist, Muscocho Explorations Limited, Magino Mine Site, personal communication, 1987) composition located in south-central Finan Township; e) the Cradle Lakes quartz-feldspar porphyry located in northwestern Bird Township and northeastern Aguonie Township; and f) numerous texturally distinct quartz-feldspar, quartz, and feldspar porphyry dikes.

All of the rocks mentioned previously are crosscut by diabase dikes. The metamorphic grade of all the rocks (excluding diabase dikes) is greenschist except within 1 km of the northern contact with the external granitoids where the rocks were subjected to amphibolite grade metamorphism (Sage 1985).

STRUCTURAL GEOLOGY

Many workers have recognized the association of regional deformation zones and shear zones with gold mineralization (*see* Macdonald 1986 for a variety of examples). Structural studies during the field season focused on the recognition of deformation zones, defined by relative intensities of deformation, and the shear zone geometries within them. These

Photo 023.1a. *Dextral shear zone within altered mafic intrusives (10 to 15 m wide), New Zone, Kremzar Gold Mines, Canamax Resources Incorporated.*

investigations will lead to a better understanding of the structural controls on gold mineralization in the study area.

The first part of this summary report deals with deformation intensity and defines some of the terms used in this study. In the second part the deformation zones are described.

DEFORMATION INTENSITY

The intensity of deformation has been systematically recorded in an attempt to define regional zones of high strain. Deformation intensity has been assessed qualitatively independent of lithology since lithological differences (or heterogeneities in the mechanical properties of rocks and minerals) can control inhomogeneous strain. For example, a felsic volcanic unit and a mafic intrusive unit may have been subjected to the same deformation history, but only the felsic volcanic rocks may reveal evidence of high strain. This may have been due to the different properties of the two rock types. As such, the deformation intensity for this example would have been recorded as "strong" for the felsic volcanic unit and "weak" for the mafic intrusive unit.

The following criteria were used in the study area to define the relative intensities of deformation observed in the field. Note that the recognition of strain intensity is dependent on the availability of strain markers and may be masked by alteration effects.

Intense Deformation

An intense deformation:

1. is characterized by a very well developed mineral foliation
2. is characterized by a primary lithology which is commonly indeterminate due to strain and alteration
3. is confined to narrow zones on the order of tens of metres wide (Photo 023.1a) or as more discrete (millimetre- to centimetre-scale) zones of sigmoidal foliations (shear zones), often exhibiting highly flattened objects such as fragments within felsic metavolcanics

Strong Deformation:

A strong intensity of deformation:

1. is characterized by a strongly developed mineral foliation (Photo 023.1b)
2. exhibits the preservation of primary lithology
3. produces a high degree of flattening; for example, in pillow selvages which initially appear as layered mafic flows, but careful examination yields rarely preserved triple junctions and relic epidotized pillow cores; other evidence consists of highly flattened and stretched fragments in felsic to intermediate tuffs, and strongly flattened amygdules and varioles in mafic pillowed flows
4. produces shear fabrics (kinematic indicators) which cannot be readily discerned

Moderate Deformation:

A moderate intensity of deformation:

1. is characterized by a moderately developed mineral foliation
2. produces some degree of flattening and stretching which may be present as described above (Photo 023.1c)
3. produces a moderate intensity of strain which is commonly observed adjacent to discrete zones of strong to intense deformation; where a moderate deformation intensity is present in a wide zone, shear fabrics such as sigmoidal foliations are absent

Weak Deformation

A weak intensity of deformation is characterized by a weakly developed preferred orientation of minerals

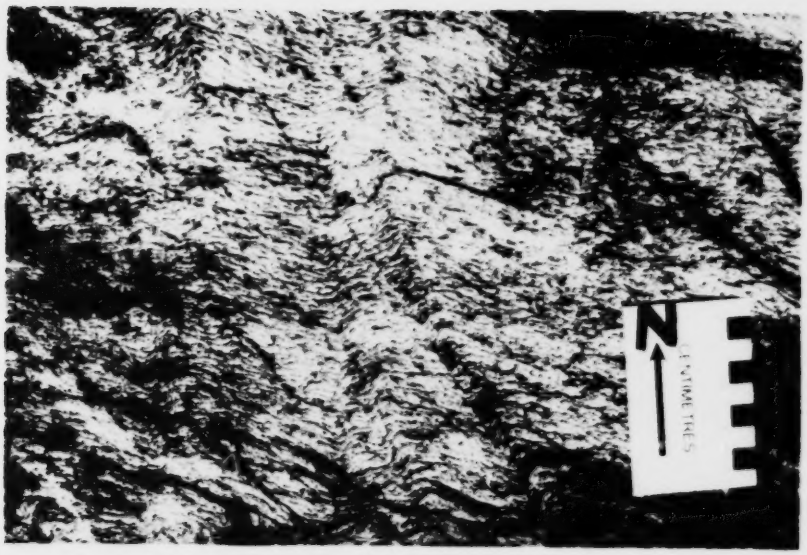


Photo 023.1b. *Strong to intense deformation expressed by highly flattened felsic volcanic rocks that exhibit a strongly developed mineral foliation.*

that defines a weak foliation. This mineral fabric can commonly be observed in the mafic intrusions of the area. Such an intensity of deformation is also common adjacent to zones of strong to intense deformation (Photo 023.1d).

Faint Deformation

A faint intensity of deformation is characterized by a very weakly developed mineral foliation; it is rarely observed in the study area.

RECOGNITION OF DEFORMATION ZONES

During the 1987 field season, two major zones of deformation were identified (Figure 023.2), the Goudreau Lake Deformation Zone (GLDZ), known informally by explorationists as the "Goudreau Shear Zone", and the Cradle Lakes Deformation Zone (CLDZ).

In the area, brittle deformation is defined by the presence of: a) brittle shears or fractures which show abrupt offsets of external markers such as quartz veins; or b) lozenge- or diamond-shaped fracture patterns. Ductile deformation is defined by the presence of sigmoidal foliations oblique to planes of shear and/or sigmoidally folded shear veins. Brittle-ductile deformation is defined by the presence of features characteristic of both brittle and ductile deformation, superimposed on one another.

The Goudreau Lake Deformation Zone (GLDZ)

The GLDZ is approximately 4.5 km in width, and has been traced for at least 25 km. It strikes 070° to 090° in a gentle arcuate form, subparallel to stratigraphy. Within this zone of high strain, there exists a major lithological contact between the felsic metavolcanic succession to the south and the mafic metavolcanic and intrusive rocks to the north. The GLDZ can be subdivided into four geographical domains, southern, northern, eastern, and western (Figure 023.2), each characterized by the different styles in which the strain is manifested. These domains are described in terms of their extent, style and intensity of deformation, shear zone kinematics, regional alteration patterns, and mineralization.

Southern Domain Preliminary work indicates an 8 km strike extent for the 2 km wide southern GLDZ. The southern domain of the GLDZ may pinch out to the east or alternatively, may be offset along a northwest-trending fault (Figure 023.2). The zone as a whole strikes 070° in the vicinity of Goudreau Lake.

On the southern part of Goudreau Lake, rocks exhibit a strong to intense state of strain over a width of at least 1 km. Felsic metavolcanic and mafic intrusive rocks appear to have similarly behaved in a dominantly ductile fashion in response to shearing. This is indicated by the presence of sigmoidal foliations (S-fabrics, Figure 023.3a) at millimetre- and centimetre-scale, whose obliquity to shear planes (C-fabrics, Figure 023.3b) indicate a dextral (right-handed) sense of shear when viewed on a horizontal surface. The oblique foliation (S-fabric) is weak relative to planes of shear (C-fabric). Locally, these two fabrics are accompanied by a third fabric which may be another plane of shear (C'-fabric, Figure 023.3c) that developed with progressive deformation.

In the vicinity of the Magino Gold Mine (Muscocho Explorations Limited) (Figure 023.2), the Webb Lake Stock behaved in a more brittle-ductile manner in response to shearing. For example, narrow shear zones of a few centimetres to tens of centimetres wide, containing central quartz veins, occur within strongly deformed rocks and exhibit the shear fabrics described above (ductile shears). In addition, discrete fractures (millimetre- and centimetre-scale) exhibit discontinuous offsets of external markers such as quartz veins (brittle shears).

Mineral lineations in the southern domain of the GLDZ are invariably horizontal to subhorizontal, indicating a dominantly horizontal component of movement. This, and other shear zone characteristics men-

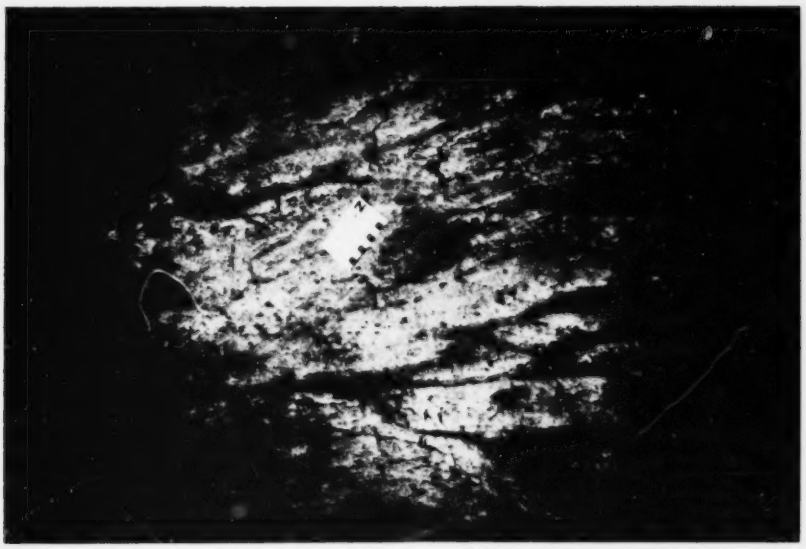


Photo 023.1c.
Moderately flattened pillows, Markes Gold Occurrence, Esso Minerals Canada.

tioned above, indicates that the southern domain of the GLDZ is largely a ductile to brittle-ductile zone of dextral transcurrent motion.

Regionally, the southern GLDZ coincides with a zone of strong alteration (Figure 023.2) where felsic to intermediate metavolcanic tuffs have been dominantly sericitized with minor chloritization. Narrow shear zones that host quartz-tourmaline and quartz-carbonate veins (parallel to shear planes) are usually highly Fe-carbonatized and/or silicified. Heather and Arias (Article 024, this volume) deal with the more specific aspects of alteration at a property scale.

Gold mineralization within the southern domain is known at four localities: the Magino Gold Mine (Muscocho Explorations Limited), the Goudreau Lake Zone, Morrison Cabin Claims, Bearpaw Portage, and Morrison No. 1 Occurrences (Canamax Resources Incorporated) (Figure 023.2; 024.1, Heather and Arias, Article 024, this volume). Shear hosted quartz-tourmaline and quartz-carbonate veins, some of which are auriferous, appear to exhibit distinct angular relationships and patterns of orientation. Similar patterns and senses of motion are exhibited by shear zones and fractures elsewhere within the southern domain. Principal shear zone orientations are 15° to 20° clockwise and/or anticlockwise to the 070° flattening plane observed in the southern domain. Both of these low angle shear orientations exhibit a dextral sense of displacement. Shear zones and fractures also occur at high angles to 070° but are less prominent here.

Northern Domain The northern part of the GLDZ is about 1 km wide and has been traced along strike for 4 km. This domain is located immediately south of the Maskinonge Lake Granitic Stock (Figure 023.2).

Narrow ductile shears (up to tens of metres wide), with concordant shear veins, and millimetre- to centimetre-scale brittle shears or fractures, cut the roughly 070°-trending foliation predominantly at high angles (i.e. as north-, northeast-, and northwest-trending shears). Foliation asymmetry (S/C-fabric) indicates that the northeast-trending structures exhibit a sinistral sense of displacement on a horizontal plane. Lineation plunges are variable in this domain, ranging from shallow to moderate in the south and steepening abruptly toward the Maskinonge Lake Stock to the north. The prominent northwest-trending shear zone at the New Zone (Canamax Resources Incorporated) is dextral and may represent the conjugate of the sinistral northeast-trending zones. Shear zones which exhibit a dextral sense of shear also occur at low angles to the roughly easterly foliation but are weakly developed.

Mafic metavolcanics immediately south of the Maskinonge Lake Stock are strongly to intensely deformed. The southeastern portion of the Maskinonge Lake Stock is characterized by weak mineral foliations and millimetre- to centimetre-scale shear zones trending northeast. Here, the sense of shear was determined to be sinistral; however, the observations are questionable since fabrics here are very weakly developed. Note that a similar shear trend is observed within the northern domain of the GLDZ. This, together with steepening lineations, suggests that the shear zones in the northern domain may be partially related to the emplacement of the Maskinonge Lake Stock.

The dominant alteration within the northern domain is manifested as biotitization, Fe-carbonatization, and chloritization of mafic metavolcanics and/or intrusive rocks (Heather and Arias, Article 024, this volume).

The principal gold deposit in the northern domain occurs at the New Zone (Kremzar Gold Mines, Canamax Resources Incorporated). Other occurrences in the northern domain of the GLDZ include: the No. 2, the No. 3, the No. 8, and the Rusty Zone (Figure 024.1, Heather and Arias, Article 024, this volume). Shear zones hosting auriferous quartz-tourmaline and quartz-carbonate veins are dominantly

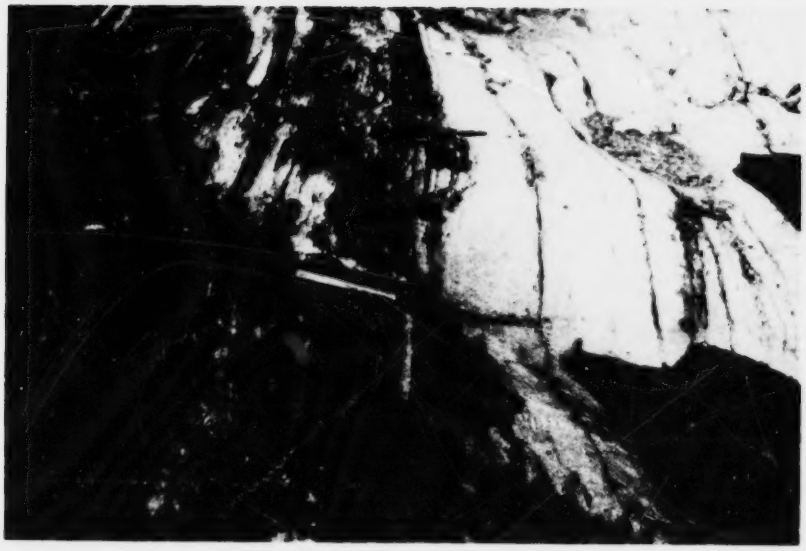


Photo 023.1d. *Weak intensity of deformation (right side) adjacent to zone of high strain (shear zone) within felsic tuffs, Morrison No. 1 Gold Occurrence, Canamax Resources Incorporated.*

oriented at high angles to the regional foliation in this domain (Figure 023.2).

Eastern Domain Present data indicates that the eastern domain of the GLDZ can be traced for a strike length of 9 km and has a width of 2 km. The regional foliation within this domain is approximately 090°. Shearing in the eastern domain is confined to narrow, brittle to brittle-ductile zones. Characteristic of brittle failure are distinct lozenge- or diamond-shaped fracture patterns best observed in quartz-feldspar porphyry dikes and sills. Brittle-ductile strain is expressed as rarely observed millimetre-scale shear zones (slip surfaces) along which discontinuous offset of centimetre-scale quartz veins is observed. Ductile shears displaying sigmoidal fabrics occur at contacts between felsic porphyry dikes and mafic metavolcanics. In contrast to the strong deformation intensity that affected the width of the southern domain, the eastern domain of the GLDZ is characterized by narrow zones (millimetre- to centimetre-scale) of intense strain, adjacent to rocks with weak to moderate deformation.

Shear zones (as well as laminated quartz-tourmaline and/or quartz-carbonate veins, fractures, and felsic porphyry dikes) within the eastern domain are dominantly parallel or at low angles (10° to 25°) to an east-trending schistosity. All of these shear zones invariably exhibit a dextral sense of movement on a horizontal plane, as determined by S/C fabrics, "horsetails" at millimetre- to centimetre-scale shear terminations, or brittle to brittle-ductile offsets of quartz veins, dikes, or lithology. Mineral lineations in this area have a consistent shallow plunge to the east, and become moderately plunging (up to 45°) eastwards toward Godin Lake (Figure 023.2).

Alteration within the eastern domain of the GLDZ is expressed locally in stockwork fractures which may have provided conduits for intense Fe-carbonatization and silicification. Sericitization and Fe-carbonatization of felsic porphyry dikes is greatest within and in the vicinity of shears. Chloritization and Fe-carbonatization of mafic intrusions and metavolcanics is common within shears in the eastern domain.

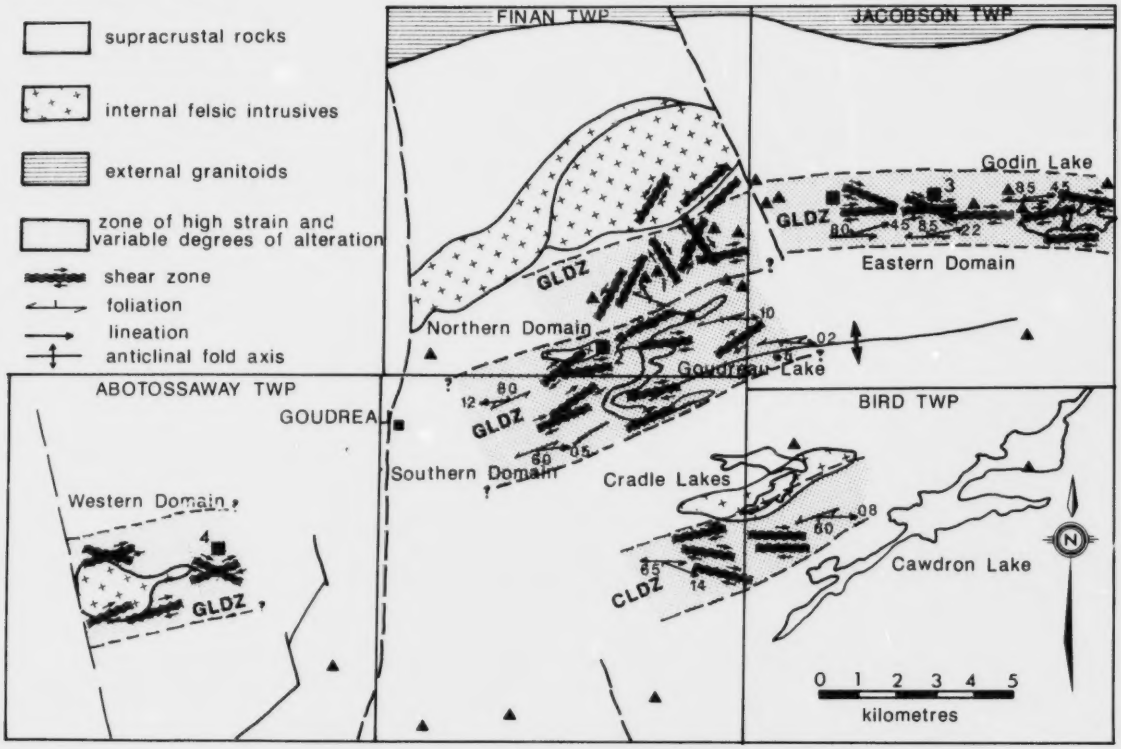
The eastern domain of the GLDZ hosts several gold occurrences, namely: the Cline Lake Gold Mine (Noranda Exploration Company Limited), the Markes Gold Occurrence (Esso Minerals Canada), the Edwards Gold Mine and others (Figure 023.2; Figure 023.1, Heather and Arias, Article 024, this volume). Brittle to brittle-ductile dextral shear zones host auriferous quartz veins which are oriented at low angles to the regional 090° foliation (Cline Lake Gold Mine, Figure 023.2b, Heather and Arias, Article 024, this volume). Auriferous laminated quartz-tourmaline veins can also be hosted by shear zones oriented parallel to the regional foliation (Markes Gold Occurrence, Figure 023.2a, Heather and Arias, Article 024, this volume).

Western Domain The western part of the GLDZ has been studied in less detail. The Murphy Gold Mine occurs within this area and has been the subject of study by many workers, the latest being the work of Studemeister (1982). Preliminary work indicates that this domain is very similar to the eastern domain. Quartz veins, hosted by brittle to brittle-ductile shear zones (exhibiting dextral senses of shear displacement), are dominantly oriented at low angles to the regional foliation.

The Cradle Lakes Deformation Zone

During the 1987 field season, another major zone of deformation, the Cradle Lakes Deformation Zone (CLDZ), was delineated (Figure 023.2), although the zone has yet to be fully documented.

The CLDZ is at least 5 km in length and may be 1 to 2 km wide, subparallel to stratigraphy. It occurs largely within feldspar-crystal tuffs, which in many places are difficult to distinguish from the feldspar-



■ mine

▲ gold occurrences

GLDZ= Goudreau Lake Deformation Zone

CLDZ= Cradle Lakes Deformation Zone

Major Gold Properties

1. Canamax-Kremzar Gold Mines-New Zone
2. Magino Gold Mine
3. Cline Lake Gold Mine
4. Murphy Gold Mine

Figure 023.2. *Relationship of deformation zones to gold deposits, regional alteration, and felsic intrusions in the Goudreau-Lochalsh area. Note the orientation and sense of displacement of discrete shear zones within high strain zones.*

porphyry intrusion (the Cradle Lakes Stock) adjacent to and partially within the CLDZ.

A large east-trending shear zone, subparallel to, and within the CLDZ, may be up to 40 m wide and can be traced for several hundred metres along strike. Rocks within this shear zone are fissile and kinematic indicators can probably best be observed in thin section. Field observations, however, indicate that the sense of displacement within the shear zone is dextral on a horizontal surface, and that mineral lineations are parallel to shallow, easterly plunging crenulation lineations.

The orientation of shear zones observed is parallel or at low angles (up to 20°), to stratigraphy/regional foliation, similar to shear zone orientations described for the southern, eastern, and western domains of the Goudreau Lake Deformation Zone.

While the Cradle Lakes Deformation Zone (CLDZ) exhibits a different style of deformation and shearing than the Goudreau Lake Deformation Zone (GLDZ), it bears many similarities to the GLDZ:

1. The CLDZ occurs close to a major lithological contact between the large succession of felsic metavolcanics to the north and the mafic metavolcanic and intrusive rocks to the south.
2. There is a high degree of alteration, largely in the form of Fe-carbonatization and sericitization, confined to the zones of high strain (Figure 023.2).
3. The proximity of the Cradle Lakes Porphyry Stock to the CLDZ can be compared to the presence of the Gutcher Lake Stock, the Webb Lake Stock, and the Cline Lake Felsic Dike Complex within the Goudreau Lake Deformation Zone and its spatial association with the Herman Lake Syenite

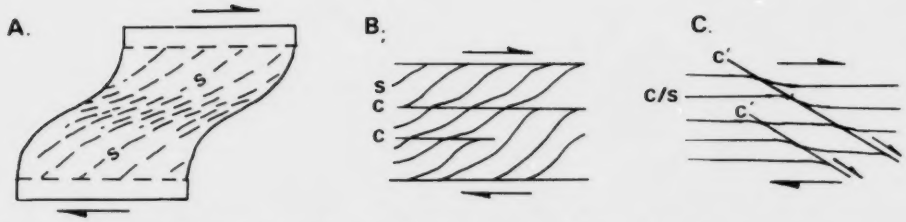


Figure 023.3. *The development of foliations by simple shear strain in a ductile shear zone.*
- *a. The variation of attitude and intensity of the penetrative foliation S, developed in the planes of flattening across the shear zone.*
- *b. With increased deformation, the C foliation, a spaced foliation, develops as planes of shear parallel to the walls of the shear zone. S is rotated into C.*
- *c. The development of C' (shear banding); the spaced foliation transects C foliation in highly strained rocks (after Roberts 1987).*

Complex and the Maskinonge Lake Stock (Figure 023.2).

Minor pyrite mineralization has been observed and a gold showing occurs north of the zone in quartz veins within mafic intrusions.

DISCUSSION AND PRELIMINARY INTERPRETATIONS

The location of the GLDZ as a whole may be controlled by the ductile to brittle-ductile southern domain of the GLDZ which was initiated at a lithological and mechanical contrast between the large felsic metavolcanic pile to the south and the sequence of mafic metavolcanics to the north. This initial deformation likely focused further deformation, which was then allowed to propagate along preexisting fractures and other planes of weakness. While progressive shearing was taking place, the pressure-temperature regime and strain rate may have decreased laterally at the ends of the GLDZ to allow for the brittle to brittle-ductile behaviour that is observed within the eastern domain.

All of the domains of the Goudreau Lake Deformation Zone described are mechanically related, although they may be characterized by different styles of deformation. Shear zones parallel and at low angles to the GLDZ exhibit a dextral sense of shear and shallowly plunging mineral lineations. This indicates that the GLDZ as a whole is governed by dextral transcurrent motion, in response to shortening and oblique compression about a northwest/southeast axis.

The systematic orientation and senses of shear zones and fractures, and the quartz veins that may occupy them, may be accommodated by a Riedel system of shears (Riedel 1929) (Figure 023.4). Poulsen (1984) recognized similar relationships for ductile and brittle shears in the Rainy Lake area of northwestern Ontario at a regional scale. Shear zones observed parallel to the 070° shear system or deformation zone (i.e. southern domain) can be identified as corresponding to D shears shown in Figure 023.4. Shears or fractures observed at a low angle to the main 070° trend, exhibiting the same (dextral) sense, may be analogous to the P and the R positions. Shears or fractures observed at a high angle to 070° may correspond to the R' orientation shown in Figure 023.4, which, consistent with field data, shows an opposite (sinistral) sense of shear. Similar relationships can be drawn for the eastern domain of the GLDZ, relative to the principal 090° orientation.

The Maskinonge Lake Granitic Stock (and conceivably the Herman Lake Nepheline Syenite Complex) may have been emplaced contemporaneously with progressive shearing as suggested by similar structures observed in the felsic intrusives and the rocks of the northern domain. While oblique compression affected the GLDZ as a whole, the emplacement of the felsic stock may have directly affected the rocks within the northern domain. The resulting north-northwest–south-southeast compression could account for the high angle conjugate shears described for the northern domain of the GLDZ.

ECONOMIC IMPLICATIONS

Gold mineralization appears to be concentrated within the GLDZ (Figure 023.2). This phenomenon may be related to many variables, such as the presence of anomalous alteration within the GLDZ relative to the surrounding rocks, the presence of felsic porphyry dikes and bodies which may have a spatial association with gold mineralization (Cherry 1983), and the lithological competency contrast between the felsic metavolcanic pile and mafic rocks to the north that may have initially attracted deformation. Little gold has been reported in areas outside of the GLDZ, but this may be related to the intensity of exploration.

The Cradle Lakes Deformation Zone bears many similarities, mentioned above, to the Goudreau Lake Deformation Zone, suggesting an economic potential for the CLDZ. However, the shear zones appear to lack corresponding quartz veins in those parts of the zone examined. Nevertheless, further economic assessment of the CLDZ is considered worthwhile.

The Goudreau Lake Deformation Zone consists of structural domains characterized by a systematic orientation of shear zones, fractures, dikes, and shear-hosted auriferous quartz veins. An understanding of shear zone/vein geometry may be significant in the prediction of favourable sites for exploration.

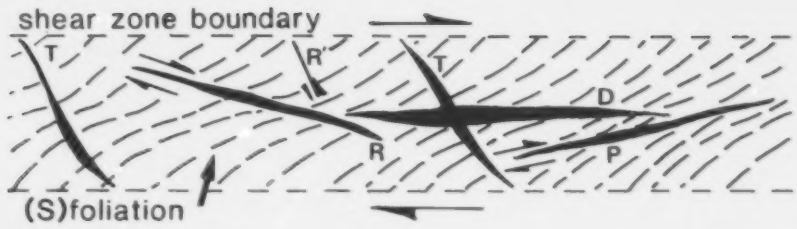


Figure 023.4. *The orientation of shear fractures and extension fractures in a brittle-ductile shear zone. The fractures are shown occupied by veins. R, low-angle Riedel shear fractures, 15° to the shear zone boundary (SZB); R', high-angle Riedel shear fractures, 75° to the SZB; P, shear fractures or reverse fractures, 15° to the SZB; T, extension fractures, perpendicular to foliation (after Roberts 1987, from experiments by Riedel 1929, and Tchalenko 1970).*

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024. Geological Setting of Gold Mineralization in the Goudreau–Lochalsh Area, District of Algoma

K.B. Heather[1] and Z.G. Arias[2]

[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto

[2]Geological Assistant, Precambrian Geology Section, Ontario Geological Survey, Toronto

INTRODUCTION

The work summarized here represents the first year of a three-year project designed to evaluate the metallogeny of gold within the Wawa Greenstone Belt. The Wawa Gold Camp comprises four gold-bearing districts: the Renabie-Missinaibi area, the Michipicoten area, the Mishibishu Lake area, and the Goudreau-Lochalsh area (Location Map). The summer of 1987 was spent in the Goudreau-Lochalsh area (Figure 024.1), located 40 km northeast of Wawa and encompassing portions of Abotossaway, Finan, Aguonie, Jacobson, Bird, and Riggs townships.

The majority of the gold showings within the Goudreau-Lochalsh area were examined (Figure 024.1); the larger ones in greater detail.

MINERAL EXPLORATION

The Goudreau-Lochalsh area hosts several past producers of both gold and iron. R.P. Sage (1983, 1984, 1985, and this volume) discusses past exploration and production. Most of the known gold showings were found by prospectors in the 1930's and have subsequently undergone numerous re-examinations since then. Excellent descriptions of some of these occurrences can be found in Gledhill (1927), Moore (1931), Burwash (1935), and Bruce (1940).

Recent intense exploration activity included two underground development projects progressing to advanced stages, as well as several surface diamond-drill programs and overburden stripping operations. At the Kremzar-New Zone Deposit, Canamax Resources Incorporated has made a production decision based on proven reserves of 1.1 million tons grading 0.235 ounce gold per ton (The Northern Miner Press, September 1, 1986). The ramp is being deepened to access the ore body on several levels in preparation for mining in 1988. Canamax Resources Incorporated are presently drilling on the Goudreau Lake Zone which has yielded very encouraging results (K. Tylee, Geologist, Canamax Resources Incorporated, Kremzar Mine Site, personal communication, 1987).

Muscocho Explorations Limited is engaged in an extensive underground exploration and development program at the Magino Gold Mine.

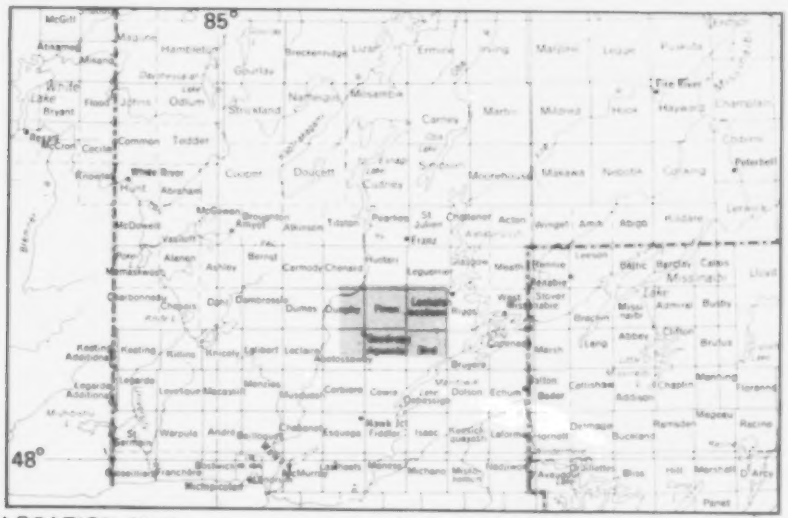
Noranda Exploration Company Limited continued diamond drilling, surface stripping, and sampling on their Cline Lake property, site of the Cline Lake Gold Mine, the largest past producer of gold in the Goudreau-Lochalsh area.

Esso Minerals Canada initiated a program of surface stripping and diamond drilling on the Markes Gold Occurrence property located immediately east of Noranda Exploration Company Limited's Cline Lake property.

Watson Lake Mines Limited conducted trenching and stripping on their property located south of Lochalsh.

GENERAL GEOLOGY

A description of the general geology of the Goudreau-Lochalsh area is given by Arias and Heather (this volume).



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

GEOLOGICAL CONTROLS ON GOLD MINERALIZATION

INTRODUCTION

Gold mineralization in the Goudreau-Lochalsh area is found in several geological settings which can be characterized in terms of host rock lithology, structure, alteration, and mineralization type. The relative importance of each of these categories as a direct or indirect control on gold mineralization varies with the scale of evaluation. This is best exemplified by discussing each of the categories in the context of regional (>1:10 000) and detailed (<1:10 000) scales.

REGIONAL CONTROLS

Host Rock

Gold mineralization is hosted by all rock types in the area excepting the diabase dikes and two granitoid intrusions, namely the Herman Lake Complex, and the Maskinonge Lake Stock. This appears to indicate that host rocks at the regional scale have no direct control on gold mineralization. Indirectly, however, the competency contrast between the large felsic to intermediate metavolcanic pile and the mafic to intermediate metavolcanics to the north and south (Figure 024.1) has served to focus the strain responsible for creating the two regional scale deformation zones which contain most of the gold occurrences.

Structure

The two regional scale deformation zones are referred to as the Goudreau Lake Deformation Zone (GLDZ) and the Cradle Lakes Deformation Zone (CLDZ) (Arias and Heather, this volume). These deformation zones are comprised of systematically arranged, brittle-ductile and brittle shear zones, as defined by Ramsay (1980) and Arias and Heather (this volume).

The GLDZ can be subdivided into four structurally distinct domains: northern, southern, western, and eastern (Arias and Heather, this volume). The southern domain of the GLDZ (Figure 023.2, Arias and Heather, this volume) is characterized as a 1 to 2 km wide, 070°-trending, zone of subparallel brittle-ductile shears. Kinematic indicators suggest the southern GLDZ is a regional zone of transcurrent dextral shear (Arias and Heather, this volume). The Magino Gold Mine (2), Canamax-Goudreau Lake Zone (3), Morrison Cabin Claims Occurrence (13), and the Bearpaw Portage Occurrence (24) all occur within the southern domain of the GLDZ (Figure 024.1). The northern, western, and eastern domains of the GLDZ (Figure 023.2, Arias and Heather, this volume) are characterized by narrow, discrete brittle and brittle-ductile shear zones with the following orientations and senses of shear displacement:

a) 020° to 035°, sinistral
b) 130° to 140°, dextral
c) 080° to 090°, dextral
d) 110° to 115°, dextral
e) 350° to 010°, variable

Gold mineralization occurs in shear zone orientations (a), (b), (c), and (d), while (e) is generally poorly mineralized. Orientations (a) and (b) predominate in the northern domain of the GLDZ, immediately south of the Maskinonge Lake Stock (Figure 023.2, Arias and Heather, this volume). Orientations (c) and (d) predominate in the western domain (i.e. Gutcher Lake Stock area) and the eastern domain (i.e. Cline Lake-Godin Lake area) of the GLDZ. (Figure 024.1; Figure 023.2, Arias and Heather, this volume).

Subparallel to the GLDZ is the CLDZ (Arias and Heather, this volume) which hosts the Reid Gold Occurrence (22), the Macleod Gold Occurrence (23), the Leitch Gold Occurrence (26) and several other small gold occurrences (Figure 024.1).

Spatially coincident with both these regional deformation zones are felsic intrusive stocks (e.g. Gutcher Lake Stock, Webb Lake Stock, Cradle Lakes Stock, and smaller dike complexes (Cline Lake area)).

A structurally distinct type of gold mineralization is found at the Michael Syndicate Shaft (9), the Canamax-Breccia Zone (10), and the Adonis Gold Occurrence (25). All of these occurrences lie within 135°- to 145°-trending, regional brittle fault zones (Figure 024.1). These fault zones are greater than ten kilometres in strike length and appear to offset the supracrustal stratigraphy. Occurrences (9) and (10) are found within one of these fault zones that forms the eastern boundary of the Maskinonge Lake Stock (Figure 024.1). Occurrence (25) is found within another of these fault zones, which forms the western boundary of the Herman Lake Complex (Figure 024.1). The auriferous portions of both these brittle fault zones are proximal to the Maskinonge Lake Stock-Herman Lake Complex (Figure 024.1).

Alteration and Mineralization

At the regional scale, there is no readily discernible alteration pattern directly related to gold mineralization. However, rocks within both the GLDZ and the CLDZ can be characterized as being zones of stronger alteration relative to the rest of the supracrustal rocks in the belt (Figure 023.2, Arias and Heather, this volume).

Regionally, within the Goudreau-Lochalsh area, there are two types of gold mineralization recognized:

a) brittle and brittle-ductile shear zone hosted
b) brittle fault breccia hosted

At the regional scale, structural controls strongly influence the mineralization types, while host rock lithology does not.

DETAILED CONTROLS

Host Rock

There are several lithological controls on gold mineralization evident at the detailed scale. All of the past producing mines are spatially associated with felsic intrusions, for example: the Murphy Lake Gold Mine (1) and several smaller gold occurrences with the Gutcher Lake Stock, the Magino Gold Mine (2) with the Webb Lake Stock, the Cline Lake (15) and Edwards (14) Gold Mines with the Cline Lake felsic

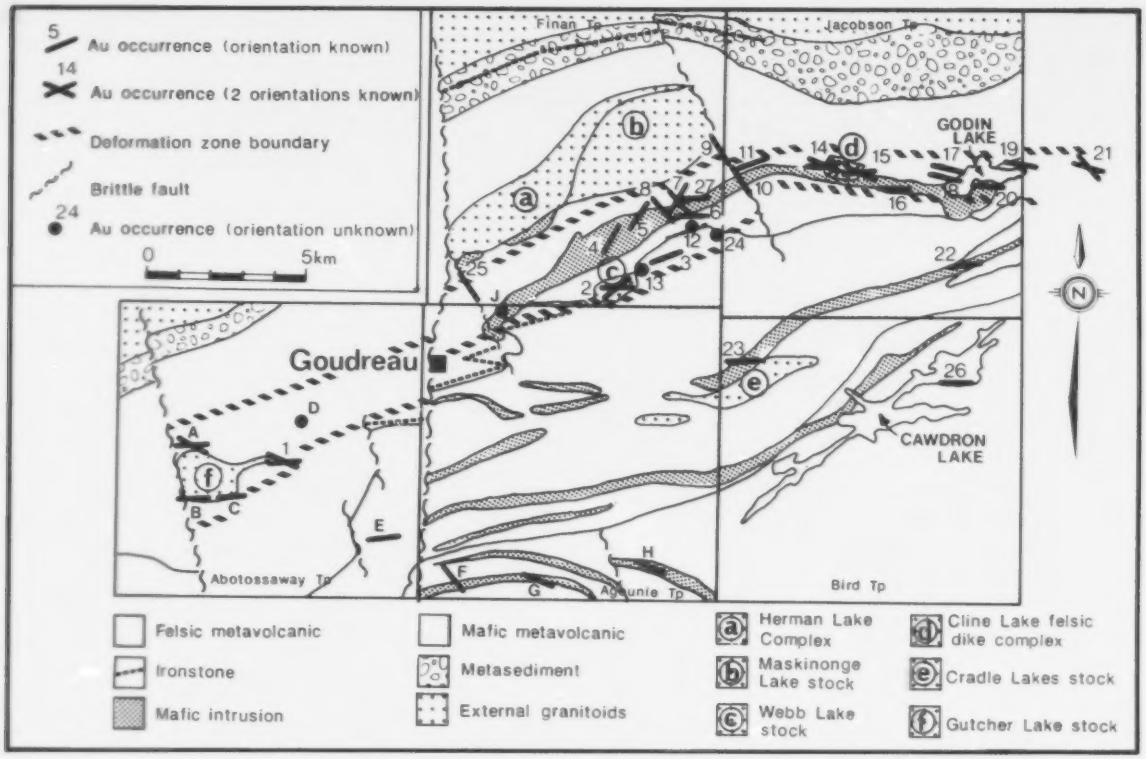


Figure 024.1. *General geology, Goudreau Lake Deformation Zone boundaries, and gold occurrence locations and orientations. The numbers beside each occurrence correspond to those in Table 023.1. The occurrences with capital letters beside them were not visited during the present study but are listed here for completeness: (A) the Ego Mine, (B) the Porter-Premier occurrence, (C) the Farquhar occurrence, (D) the Banville-Page occurrence, (E) the Kozak occurrence, (F) the Priest occurrence, (G) the Slate Lake occurrence, (H) the Smith Highgrade occurrence, (J) the Noranda Exploration Company Limited Anomaly 1-81 occurrence.*

dike complex (Figure 024.1). Numerous other gold occurrences are found in close proximity to felsic intrusions (e.g. Canamax-Goudreau Lake Zone (3)), along the contact with felsic intrusive dikes (Figure 024.2a, Markes Gold Occurrence (16)), or hosted within felsic intrusive dikes (e.g. Morrison Cabin Claims (13)). The Canamax Kremzar-New Zone (8) and several smaller occurrences are found flanking the southern rim of the Maskinonge Lake Stock (Figure 024.1).

Gold mineralization is commonly hosted exclusively within a single lithology such as mafic intrusion (Figure 024.2c, Kremzar-New Zone (8)), felsic intrusion (Figure 024.2d, Magino Gold Mine (2)), felsic metavolcanic (e.g. Bearpaw Portage Occurrence (24)), or pyrite-siderite ironstone (e.g. Canamax-Pine Zone (11) and Canamax-Morrison No. 1 (12)). Gold mineralization can also be hosted by several lithologies within a single occurrence (Figure 024.2b, Cline Lake Gold Mine 15)).

Structure

The regional structural patterns are duplicated at the deposit and outcrop scales. Each of the gold occurrences in the Goudreau-Lochalsh area may contain up to six systematically oriented brittle and/or brittle-ductile shear zones ranging in width from a few millimetres up to several metres. These shear zones can be classified into six groups based on their orientation (Table 024.1 and Figure 024.3b). For each gold occurrence all the brittle (B) and brittle-ductile (BD) shear zone orientations were measured along with any apparent sense of shear displacement (i.e. sinistral (s), dextral (d), or not distinguishable (n.d.)). Several preliminary observations can be made from the data in Table 024.1:

(a) Up to six shear zone orientations may be present at an individual gold occurrence but only one or two of those orientations appear to contain significant gold mineralization.

(b) Groups (1) through (5) host gold mineralization, while group (6) does not.

(c) A consistent sense of shear displacement within some of the shear zone orientation groups does exist (e.g. Groups (1) and (2) are dextral, while a lack of consistency exists for others (e.g. Groups (3) and (6)).

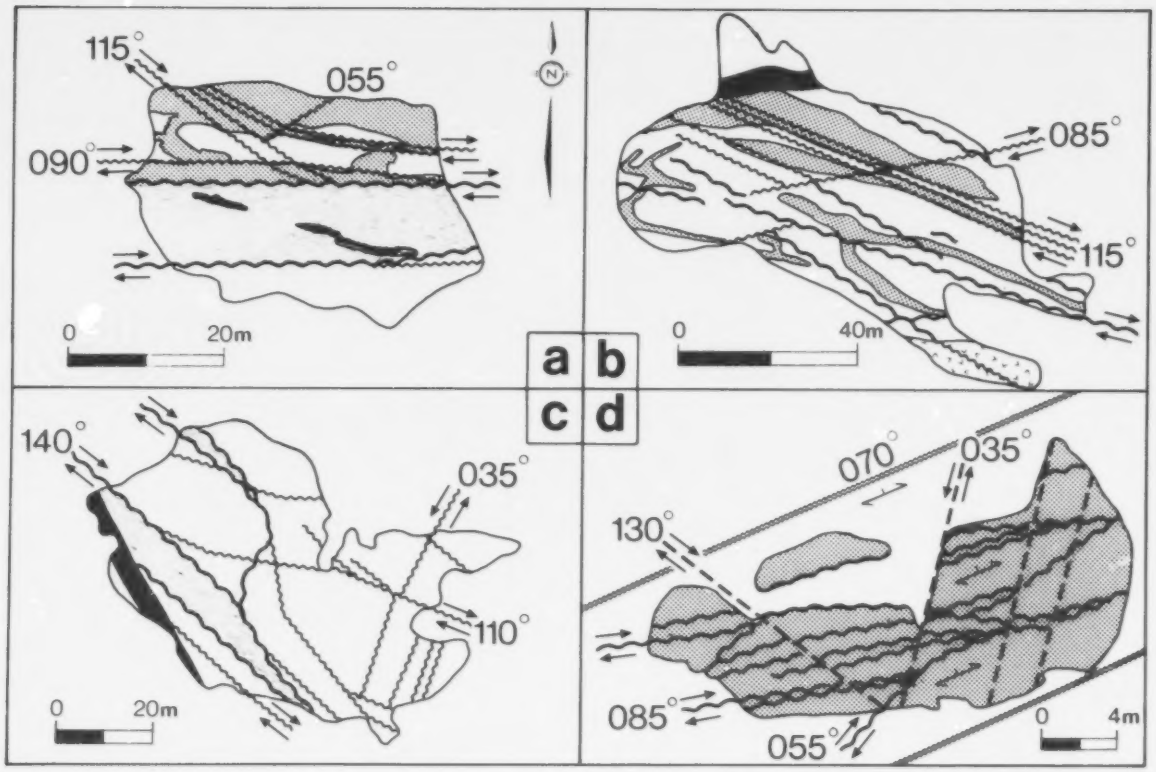


Figure 024.2. *Simplified geology with shear zone orientations and senses of shear displacement for the: (2a) Markes Gold Occurrence (16); (2b) Cline Lake Gold Mine (15); (2c) Canamax Kremzar-New Zone (8); (2d) Magino Gold Mine (2).*

LEGEND: *Diabase (black), Felsic Intrusion (stippled), Felsic Metavolcanic (v's), Mafic Metavolcanic or Intrusion (white), Auriferous Shear Zone (heavy sinuous line), Non-aurifeous Shear Zone (light sinuous line), Wide Shear Zone (wavy pattern).*

(d) Shear zones of identical orientation and shear displacement sense may be brittle-ductile gold-bearing structures at one occurrence, while at another occurrence they are brittle and non-gold-bearing, or vice versa (Figure 024.3).

(e) Geographically distinct areas can be defined within which certain shear zone orientation groups are dominant (Figure 023.2, Arias and Heather, this volume).

(f) Gold occurs in both brittle and brittle-ductile shear zones.

Generally, one of the shear zone trends will be dominant and host significant gold mineralization (e.g. the 035° trend at the Canamax-No. 2 Zone (5)). While locally, two shear zone trends may host gold mineralization with one still being dominant (Figure 024.2b, 085° and especially the 115° trends at the Cline Lake Gold Mine (15)).

Some of the auriferous shear zones can be comprised of two or more obliquely oriented, shear-hosted auriferous vein structures (Figure 024.2d, the 070°-trending shear zone containing 085° and 050° veins at the Magino Gold Mine (2)).

A close relationship between each of the groups of shear zone orientations (1 through 5) is indicated by the following field relationships:

(a) At any one of the gold occurrences, brittle-ductile shear zones of different orientations are seen splaying off one another with no apparent cross-cutting relationship (e.g. the 085° and 050° shear-hosted veins at the Magino Gold Mine (Figure 024.2d), or the 090° and 115° shear zone trends at the Markes Gold Occurrence (Figure 024.2a).

(b) A brittle shear zone of 'X' orientation offsets a brittle-ductile shear zone of 'Y' orientation at one occurrence, while at another occurrence the first orientation 'X' is a brittle-ductile shear zone offset by a brittle shear zone of the second orientation 'Y'. Where X and Y are any of the shear zone orientation groups in Table 024.1. (For examples compare Figures 024.3c, d, e, and f).

Intersections between shears of differing orientation appear to be favourable sites for higher grade shoots of gold mineralization at some occurrences (Figure 024.2b, Cline Lake Gold Mine (15)).

TABLE 024.1. LIST OF GOLD OCCURRENCES VISITED DURING THE PRESENT STUDY WITH BRITTLE AND BRITTLE-DUCTILE SHEAR ZONE ORIENTATIONS OBSERVED AT EACH.

MAP No.	Gold Occurrence Name	Shear Zone Orientation Groups**					
		(1)	(2)	(3)	(4)	(5)	(6)
1	Murphy Gold Mine	*,BD,d	*,BD,d	BD,d?	B,s	B,n.d.	-
2	Magino Gold Mine	*,BD,d	?	*,BD,d?	-	B,d	B,s
3	Canamax Goudreau Lake Zone	NOT EXPOSED AT SURFACE					
4	Canamax - No. 3 Zone	BD,d	B,d	-	*,BD,s	B,n.d.	B,n.d.
5	Canamax - No. 2 Zone	B,n.d.	B,n.d.	BD,n.d.	*,BD,s	B,n.d.	-
6	Canamax - No. 8 Zone	*,BD,d	B,n.d.	BD,n.d.	BD,n.d.	-	B,n.d.
7	Canamax - Rusty Zone	BD,d	BD,d	*,BD,s?	BD,s	*,BD,d	B,d
8	Canamax - Kremzar - New Zone	B,n.d.	BD,d	-	BD,s	*,BD,d	B,n.d.
9	Michael Syndicate Shaft	-	-	-	-	*,B,n.d.	-
10	Canamax-Breccia Zone	-	-	-	-	*,B,n.d.	-
11	Canamax-Pine Zone	*,BD,n.d.	-	-	-	-	-
12	Canamax-Morrison No. 1						IRONSTONE HOSTED
13	Morrison Cabin Claims	*,BD,n.d.	-	-	-	-	B,n.d.
14	Edwards Gold Mine	*,BD,d	*,BD,d	-	-	-	-
15	Cline Lake Gold Mine	*,BD,d	*,BD,d	BD,n.d.	-	B,n.d.	B,d
16	Markes Gold Occurrence	*,BD,d	BD,d	BD,n.d.	-	-	B,n.d.
17	Laughlin Gold Occurrence	-	*,BD,d	BD,s?	-	-	-
18	McColl Gold Occurrence	-	*,BD,d	-	-	-	-
19	3-Mile Post Gold Occurrence	-	*,BD,d	B,n.d.	B,n.d.	B,n.d.	B,n.d.
20	Archibald Gold Occurrence	NOT EXPOSED AT SURFACE					
21	Watson Lake Property	BD,d	*,BD,d	BD,n.d.	-	*,BD,d?	-
22	Reid Gold Occurrence	*,BD,d	-	BD,s	BD,s	BD,d?	
23	MacLeod Gold Occurrence	*,BD,d	-	BD,s	B,s?	B,d?	-
24	Bearpaw Portage Occurrence	*,BD,d	-	-	-	-	-
25	Adonis Gold Occurrence	-	-	-	-	B,n.d.	-
26	Leitch Gold Occurrence	*,BD,n.d.	-	-	-	-	-
27	Canamax-Pyrrhotite Zone	*,BD,d	-	-	-	-	-

** SHEAR ZONE ORIENTATION GROUPS

(1)	080o - 090o	BD	=	Brittle-ductile shear zone
(2)	105o - 120o	B	=	Brittle shear zone
(3)	045o - 065o	d	=	dextral shear displacement
(4)	025o - 035o	s	=	sinistral shear displacement
(5)	130o - 150o	*	=	hosts significant gold
(6)	350o - 010o	n.d.	=	shear sense not determined
		?	=	shear sense not conclusive
		-	=	shear sense not recorded

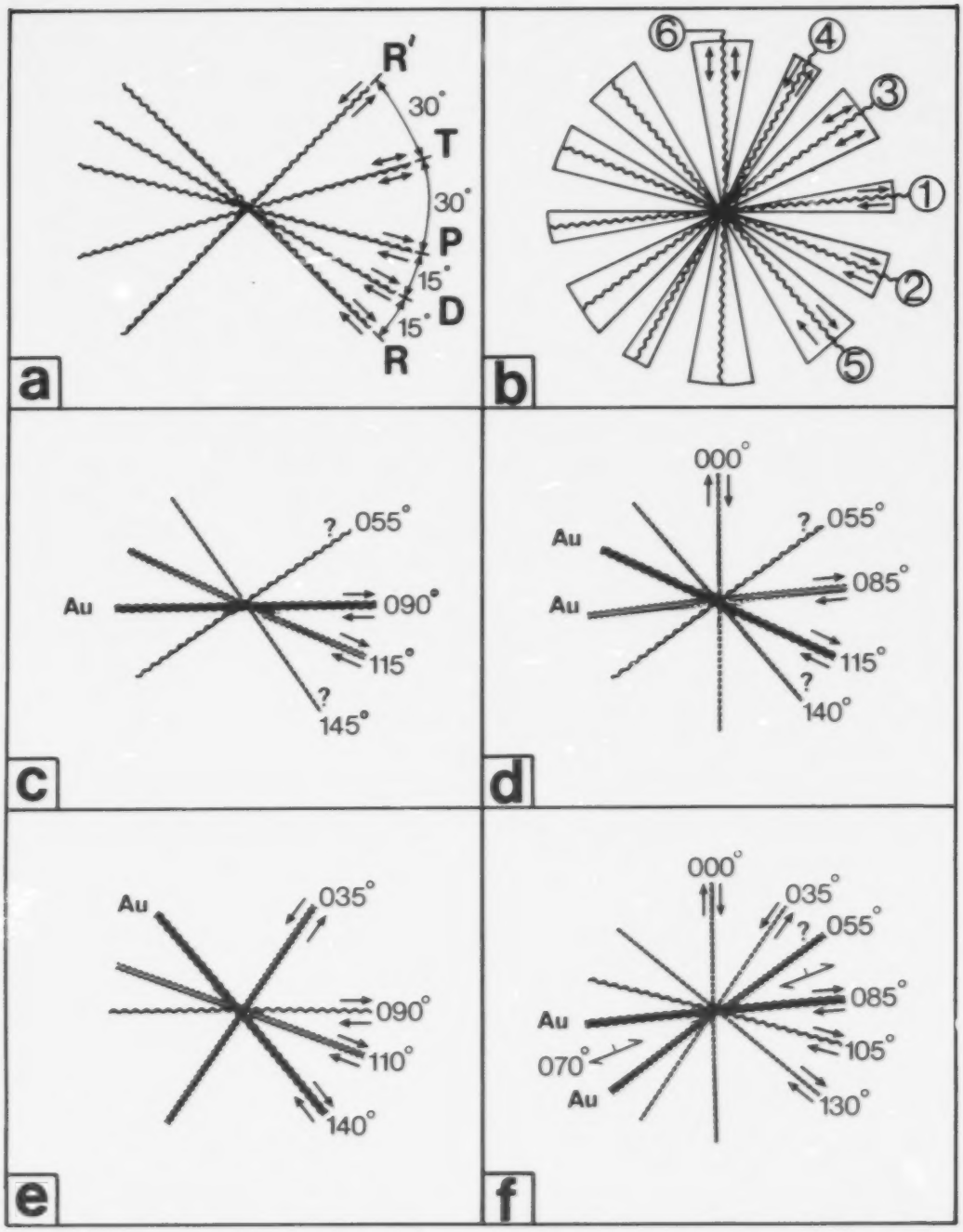


Figure 024.3. *Rose diagram representations of shear zone orientations and senses of shear displacement for: (3a) Theoretical (ideal) Riedel shear systems; (3b) the regional auriferous shear zone groups from the Goudreau-Lochalsh area. Circled numbers correspond to those in Table 1; (3c) the Markes Gold Occurrence (16);(3d) the Cline Lake Gold Mine (15);(3e) the Canamax Kremzar-New Zone (8);(3f) the Magino Gold Mine (2).*

LEGEND: *Brittle-ductile shear zones are denoted by three styles of sinuous lines: strong (triple line), moderate (double line), weak (single line). Brittle shear zones are denoted by a straight dashed line.*

Alteration and Mineralization

There is a readily discernible alteration pattern related to gold mineralization. All of the gold deposits, with the possible exception of the brittle fault breccia hosted type, are characterized by variable amounts of carbonatization (Fe-carbonate and/or calcite), silicification, sulphidization (pyrite and/or pyrrhotite), biotitization, sericitization, feldspathization (potassic-feldspar or albite), and/or chloritization. Original host rock composition is an obvious control on the alteration types that will be present at any single gold occurrence. Adjacent to the auriferous zones the mafic rocks are generally altered to biotite, Fe-carbonate, pyrrhotite and/or pyrite, quartz, and minor potassic-feldspar while chlorite, calcite, and minor pyrrhotite and/or pyrite are found peripherally. Within felsic rocks the alteration proximal to the auriferous zones is manifested as quartz, sericite, pyrite and/or pyrrhotite, Fe-carbonate, and locally albite. The alteration within the ironstones is cryptic due to the similarity between the original pyrite-siderite mineralogy and the subsequent, Fe-carbonate dominated hydrothermal alteration.

The brittle fault breccia type of mineralization is characterized by pervasive silicification, quartz vein stockworking, chloritization, and minor calcite carbonatization.

The following mineralization types can be identified at the detailed scale and are subtypes of those described for the regional scale:

(a) brittle-ductile shear-hosted quartz veins (e.g. the Canamax Kremzar-New Zone Deposit (8))

(b) brittle shear-hosted quartz veins (e.g. locally at the Cline Lake Gold Mine (15))

(c) brittle fault breccia-hosted (e.g. Michael Syndicate Shaft (9))

(d) brittle-ductile shear-hosted disseminated sulphides (e.g. Canamax-Pyrrhotite Zone)

(e) ironstone-hosted related to (a) or (c) above (e.g. Canamax-Pine Zone (11))

DISCUSSION

Work at the regional (Arias and Heather, article 023, this volume) and detailed scales has identified a strong structural control of the gold mineralization in the Goudreau-Lochalsh area. Shear zone orientations and senses of shear displacement documented at the regional scale are similar to those observed at the deposit and outcrop scales. The systematic orientation of shear zones, the consistent sense of shear displacement within shears of similar orientation, the angular relationship between individual shear zones (Figures 024.3a and b), and the apparent synchronous development of each shear zone orientation, all seem consistent with features found in Riedel shear systems (Cloos 1928; Riedel 1929; Hills 1963 and Tchalenko 1970). Figure 024.3 depicts rose diagrams of theoretical Riedel shear orientations (024.3a), regional-scale auriferous shear orientations from the Goudreau-Lochalsh area (024.3b), and detailed-scale shear orientations from individual gold occurrences within the Goudreau-Lochalsh area (024.3c, d, e, and f). A comparison of the theoretical (ideal) Riedel shear orientations (Figure 024.3a) and those hosting gold mineralization in the Goudreau-Lochalsh area (Figure 024.3b) reveals a close similarity. Likewise the shear orientations seen at the deposit scale (Figures 024.3c, d, e, and f) are consistent with the ideal Riedel shear orientations.

Gold mineralization in the Goudreau-Lochalsh area has the following characteristics:

(1) Gold is found in quartz veins associated with discrete brittle-ductile shear zones within both the Goudreau Lake Deformation Zone (GLDZ) and the Cradle Lakes Deformation Zone (CLDZ).

(2) These discrete shear zones have systematic orientations at both the regional and detailed scales.

(3) The GLDZ can be subdivided into domains within which certain shear zone orientations appear more favourable for gold mineralization relative to others.

(4) There is a spatial relationship between felsic intrusions and gold mineralization.

(5) Locally, the authors have recognized that felsic dike contacts are particularly favourable sites for gold mineralization.

(6) Alteration associated with gold mineralization consists of variable amounts of biotite, sericite, Fe-carbonate, quartz, chlorite, potassic-feldspar, calcite, pyrite and pyrrhotite.

ACKNOWLEDGMENTS

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Abitibi Subprovince

025. The Abitibi Initiative—Abitibi Greenstone Belt

J.A. Fyon

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

Systematic, detailed township mapping continues to provide the essential geological basemap coverage for Ontario; however, a comprehensive regional perspective can only be achieved by collaboration between members of an integrated working group, addressing problems of mutual interest. Because the rapid evolution of the geological sciences has made it difficult, if not impossible, for an individual geologist to be a "complete" scientist, the "group" concept provides a milieu in which the different scientific backgrounds and technological experiences of individuals are united to produce a group having a common, focused objective. This "group" is stronger and more capable of addressing complex geoscientific problems than any one individual.

The Abitibi Greenstone Belt is one of the largest Archean greenstone belts in the world and has accounted for a large proportion of Ontario's Archean mineral production. Many geologists have studied aspects of the Abitibi Greenstone Belt over the years, but we do not yet have a full understanding of its geological framework and mineral potential. The Precambrian Geology Section of the Ontario Geological Survey, in 1987, initiated a comprehensive geological study of the belt. This initiative will be multidisciplinary, drawing upon and integrating the diverse scientific and technological skills and perspectives of a group of geologists. The objectives of the program are to acquire a comprehensive understanding of the evolution of the Abitibi greenstone belt, and of the relationship between that evolution and specific geological and mineralization characteristics of the belt. Emphasis will be placed upon a) lithological distribution, b) structural relationships, c) the extent and distribution of metamorphism and alteration, d) intrusive history and its relationship to metamorphism and alteration, e) mineralization, and f) the relationship between magmatic and tectonic features and the types of and spatial and temporal distributions of mineralization.

Several studies within the initiative have begun. Information from previous and on-going geological studies are being incorporated into an updated geological compilation. This compilation will be used to define areas where geological data are either lacking or insufficient and where future projects will be necessary to address specific problems. Three projects, reported elsewhere in this volume, comprise the current field-based components of the initiative. D.W. Piroscho and Karen Kettles began a two-year mapping project in Whitney and Tisdale Townships, focusing this year in southern Whitney Township along a zone of deformation parallel to, but south of, the Destor-Porcupine Fault Zone. Preliminary results from this work suggest a novel interpretation of the Destor-Porcupine zone of deformation. Soussan Marmont continued mapping in the Detour-Hopper-Sunday Lakes area; this work has demonstrated the similarity of the area to the Chibougamau-Matagami greenstone belt and its dissimilarity to the central Abitibi Greenstone Belt. D.J. Good began a study of magmatic mineral deposits, with the intent of developing a model to describe remobilized sulphide settings and adding to the existing database for platinum group elements (PGE) in mafic and ultramafic rocks, both in the Abitibi Greenstone Belt and elsewhere in Ontario. Geochronological data, provided by Soussan Marmont in collaboration with the Jack Satterley Laboratory at the Royal Ontario Museum, continues to provide essential constraints on the magmatic and metallogenic evolution of the Abitibi Greenstone Belt.

These projects comprise components of the multidisciplinary initiative. They address different topics: the structural evolution in a well-mineralized area, the volcano-tectonic evolution of an area with limited known mineralization and unknown potential to host other deposits, the processes responsible for accumulation of metals in magmatic rocks, and the chronological development of major belt-building events. Each will continue to provide fundamental geological data to the development of the comprehensive model for the evolution of the Abitibi Greenstone Belt. It is of utmost importance to test the multiple working hypotheses which describe an evolutionary model of the Abitibi greenstone belt. In this regard, a planned, deep crustal reflection seismic traverse, running northerly across that segment of the Abitibi Greenstone Belt near Kirkland Lake, will provide the third dimensional perspective of that portion of the Abitibi Greenstone Belt. This work is being carried out through cooperative research with G.F West, University of Toronto, and is being coordinated with the major Canadian Lithoprobe Program. This work will have been conducted during the fall of 1987 and preliminary results should be available in the spring of 1988. The integration of these extremely important geophysical data, with the empirical field observations and geochemical data, will provide a powerful framework upon which to construct and test a conceptual model that describes the evolution of the Abitibi Greenstone Belt.

026. Geology of South Whitney Township With Emphasis on Structural Geology and Gold Potential, District of Cochrane

Darwin Piroshco and Karen Kettles

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

During the 1987 field season, a five-person field crew completed the first summer of a two-summer mapping project (scale 1:10 000) of Tisdale and Whitney Townships located between Latitudes 48°27'N and 48°32'N and Longitudes 81°04'30"W and 81°20'W. The City of Timmins is located in the west-central portion of Tisdale Township.

The purpose of the project is to update the geological database of Tisdale and Whitney Townships which contain the majority of the past and producing gold mines in the Porcupine Gold Camp, and to provide geological criteria for future exploration for gold mineralization.

The main objective of the project is to better define the patterns of, and relationships between, lithologies, structural elements, metamorphism/alteration, and gold deposits. A solid framework for this project is provided by several previous studies in the Timmins area which are too numerous to mention in this report. Most are summarized in the latest reports on the Timmins area by Pyke (1982), Hodgson (1983b), and Mason and Melnik (1986).

This report summarizes the results from scale mapping at 1:10 000 of south Whitney Township (Figure 026.1) which represents that portion of the project area covered during the 1987 field season.

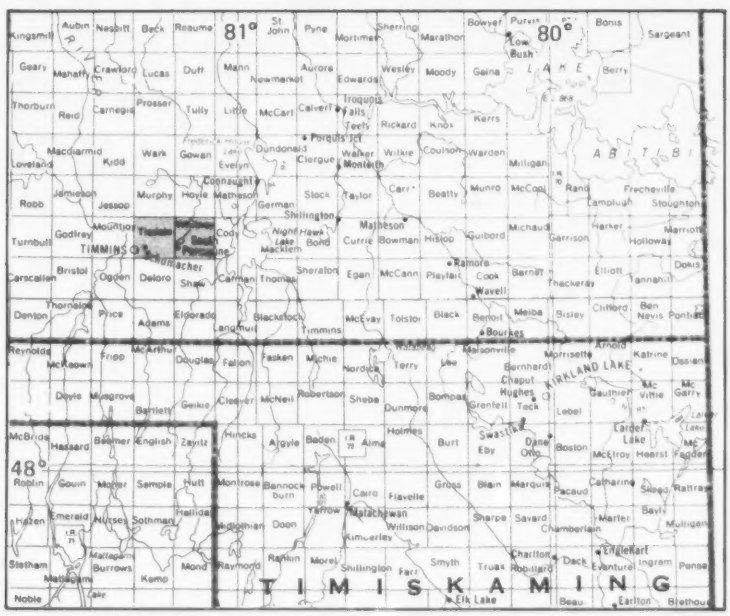
MINERAL EXPLORATION

Prospecting, exploration, and mining for gold have been continuous in the Timmins area in various degrees of intensity since the early 1900s. It is beyond the scope of this report to summarize the history of work and current activities in the region. The most comprehensive but somewhat out-of-date overview of the mining history in Tisdale and Whitney Townships is provided by Ferguson *et al.* (1968) and Hodgson (1983b).

REGIONAL GEOLOGY

STRATIGRAPHY

Mapping by Burrows (1915, 1924), Hurst (1939), Dunbar (1948), Ferguson (1959), Carlson (1967), Leahy (1971), Roberts (1981) and Pyke (1970, 1972, 1975b, 1978a and b, and 1982) forms the base for the current geological interpretations of the Timmins area (Figure 026.1). The most recent and comprehensive regional map of the Timmins area is provided by Pyke (1982). Stratigraphic interpretations and correlations of the metavolcanics and metasediments have



LOCATION MAP Scale : 1 : 1 584 000 or 1 inch to 25 miles

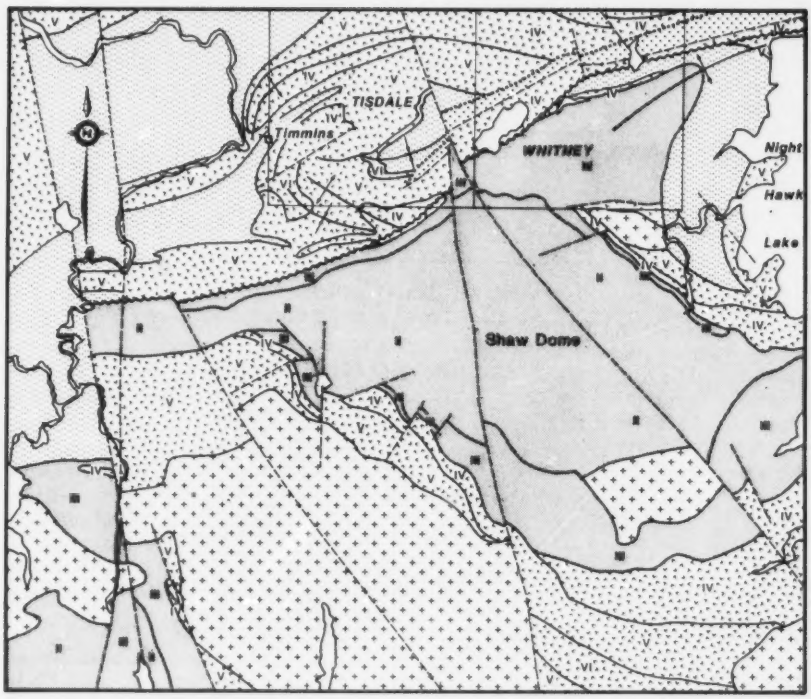


Figure 026.1. *General geology of the Timmins area (modified after Pyke 1982).*

Legend

Metasedimentary Rocks

- Younger (Timiskaming)
- Older

Tisdale Group

- VI Upper Metavolcanic Formation
- V Middle Metavolcanic Formation
- IV Lower Metavolcanic Formation

Deloro Group

- III Upper Metavolcanic Formation
- II Middle Metavolcanic Formation
- I Lower Metavolcanic Formation

Granitic Rocks

Symbols

- Geological boundary
- Unconformity
- Destor–Porcupine Fault
- Fault
- Anticlinal axis
- Synclinal axis

been provided by Burrows (1924), Hurst (1936), Dunbar (1948), Pyke (1982) and Hodgson (1983a). A brief description and distribution based on Dunbar's (1948), Pyke's (1982), and Hodgson's (1983a) interpretations, is shown in Table 026.1 and Figure 026.1.

Rocks of the Deloro Group, as defined by Dunbar (1948) and Pyke (1982), are only known to occur south of the Destor-Porcupine Fault (Figure 026.1). Rocks of the Tisdale Group, as defined by Dunbar (1948) and Pyke (1982), occur north of the fault but have also been interpreted by Pyke (1982) and Jensen (1981) to occur south of the fault. The correlation of the Tisdale Group rocks across the fault is based mainly on similar lithological/geochemical (komatiitic/ultramafic to tholeiitic/mafic to calc-alkalic/felsic) trends and sequences. This correlation has not been firmly established. Metasediments of the Porcupine Group, as defined by Lorsong (1975), are in this study referred to as "Older" and "Younger" sediments (Figure 026.1), a subdivision proposed by Hodgson (1983a) based on Dunbar's (1948) interpretation.

STRUCTURAL GEOLOGY

The Tisdale Group and metasediments north of the Destor-Porcupine Fault occur as a steeply dipping, north-overturned, homoclinal sequence which shows a high degree of complex folding in the southern half

TABLE 026.1. DESCRIPTION OF STRATIGRAPHY UNITS IN THE TIMMINS AREA BASED ON INTERPRETATIONS OF PYKE (1982) AND HODGSON (1983) - to accompany Figure 026.1.

Stratigraphic Unit	Description
Younger Metasediments	Wacke and siltstone at the base with interbedded lithic arenite and conglomerate at the top
Older Metasediments	Siltstone, wacke, and mafic tuff
Formation VI	Dominantly felsic, calc-alkalic pyroclastic rocks
Formation V	Dominantly iron-rich tholeiitic mafic volcanic rocks
Formation IV	Ultramafic and mafic komatiites at the base and interlayered ultramafic komatiites and Mg-tholeiitic mafic volcanic rocks at the top
Formation III	Calc-alkalic intermediate to felsic volcanic rocks and iron formation
Formation II	Calc-alkalic mafic and intermediate volcanic rocks and ultramafic intrusive rocks
Formation I	Not exposed in the Timmins area, mainly ultramafic volcanic rocks

of Tisdale Township in the vicinity of the major past and present producing gold mines. There has not been a comprehensive, structural study of the Tisdale Group rocks but there have been several studies confined mainly to the southern half of Tisdale Township. It is beyond the scope of this summary to review and discuss all of the published structural data and interpretations.

The Deloro Group rocks south of the Destor-Porcupine Fault are confined to a northwest-trending, elongate, rectangular structure referred to as the Shaw Dome (Pyke 1982). The interpretation of this structure as a dome is based on: 1. the regional stratigraphic framework (Pyke 1982) which shows the rocks rimming the structure to be a volcanic cycle younging outwards and; 2. the correlation of this volcanic cycle with the younger Tisdale Group. Structural data to support this interpretation is, however, lacking, and the complex structural relationships of the lithological units within and surrounding the dome are poorly understood.

MINERAL DEPOSITS

Ferguson *et al.* (1968) and Fyon and Crocket (1983) have provided the most recent and comprehensive overviews of the ore deposits in the Timmins area and the reader is referred to these publications for detailed information. South of the Destor-Porcupine Fault, in a region including the 1987 study area, significant gold deposits have not been discovered. Several minor past producing mines and unexploited deposits occur south of the fault in south Deloro Township (immediately west of Whitney Township) and in Cody Township (immediately east of Whitney Township) near the northern end of Night Hawk Lake (Map 2222 of Leahy 1971).

GEOLOGY OF SOUTH WHITNEY TOWNSHIP

INTRODUCTION

An area approximately 50 km^2 was mapped in south Whitney Township corresponding to an area extending from the Destor-Porcupine Fault south to the township boundary (Figure 026.2). Outcrop is abundant in the southwestern portions of the map area but diminishes rapidly towards Goose Creek. Areas to the east of Goose Creek were not mapped this field season.

In Pyke's (1982) stratigraphic interpretation, the volcanic units shown in Figure 026.2 are equivalent to the top of Formation II and Formation III of the Deloro Group and the base of Formation IV of the Tisdale Group, and occupy the northeasterly portion of the Shaw Dome. The units generally trend northeast and dip shallowly or moderately northwest in the southern portions, but dip steeply southeast or northwest in the northern portions of the mapped area. The following is a brief description of the lithological units and their distinctive features.

DESCRIPTION OF LITHOLOGIES

Komatiitic Flows

A series of highly carbonatized units, interpreted to be extrusive ultramafic flows, occur in several linear, fault-bounded bands and blocks in the southern half of Whitney Township. They are spatially associated with ultramafic intrusions, felsic metavolcanics and iron formation (Figure 026.2). These rocks were mapped by Pyke (1982) as carbonatized rocks of unknown origin, or in some cases, as ultramafic intrusions. The recognition of these rocks as ultramafic flows is based on their overall similarity with rocks positively identified as ultramafic flows in north Whitney Township. These similarities include the pres-

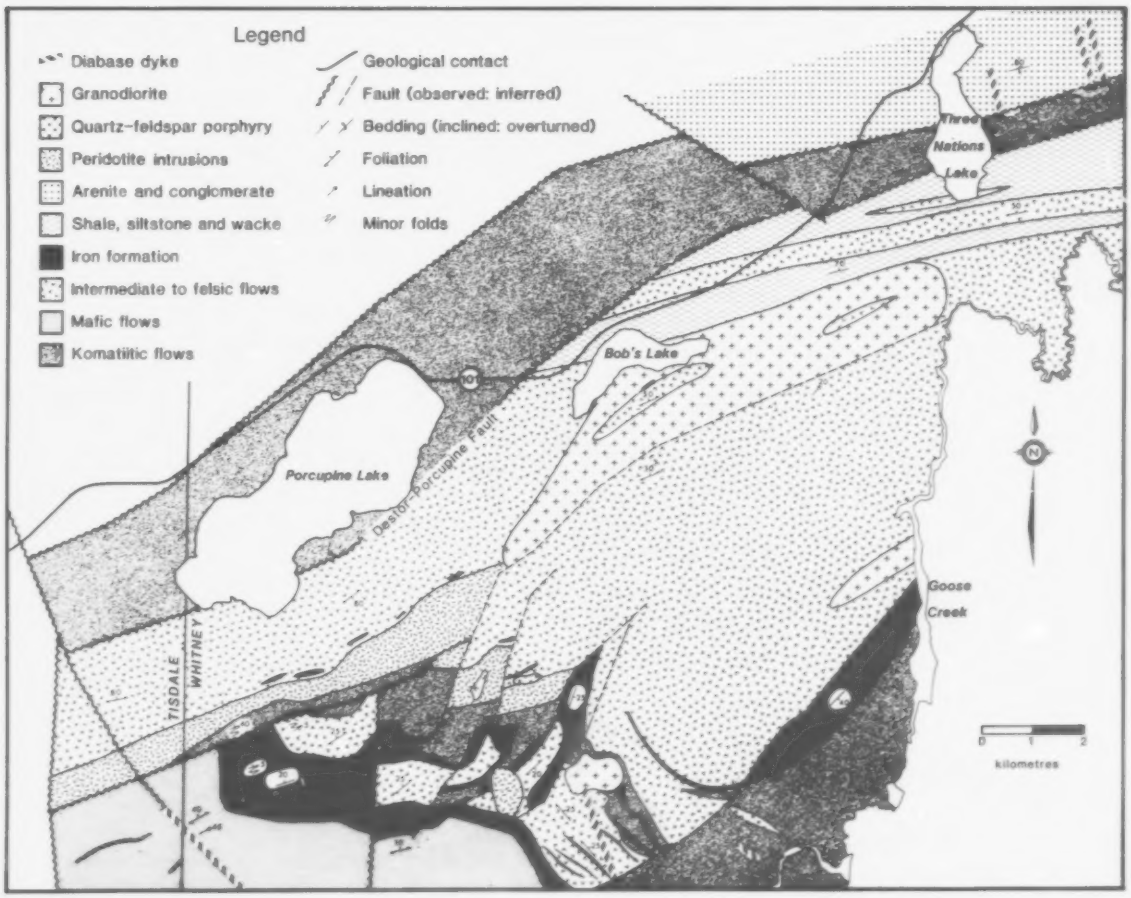


Figure 026.2. *Geology of South Whitney Township.*

ence of spinifex textures, polysuturing and elephant skin textures, and consistent concordant relationships with adjacent lithologies.

The main expression of this lithology is as a rusty weathered, schistose rock which commonly displays crude layering, defined by recessive weathered foliated, chlorite-rich bands, and resistant weathered carbonate-rich bands. The second less abundant type, which is generally gradational with the schistose type, includes the massive, polysutured, and spinifex-textured rock displaying characteristic elephant skin texture and in one instance, pillows.

Mafic Flows

Basaltic to andesitic calc-alkalic rocks of the Shaw Dome form an east-trending sequence in the south and southwestern portions of the map area. The sequence is flanked to the north and northeast by a structurally complex sequence of iron formation, ultramafic, and dacitic volcanic units. To the northwest, the mafic volcanics are truncated by a fault (Figure 026.2). Within the map area, internal stratigraphy could not be defined within this sequence which consists dominantly of massive to amygdaloidal flows that locally display pillowed, brecciated, and schistose phases. These phases or sub-units are typically narrow discontinuous bodies which are gradational with the massive flows. The breccia sub-

units do not display bedding and typically are monolithic breccias, composed of subangular to subrounded felsic clasts (2 mm to 5 cm in diameter). Schistose varieties are most abundant in the northern part of the unit.

Intermediate to Felsic Flows

Intermediate to felsic volcanic rocks are abundant in the northwestern and southeastern portions of the map area. In the southeast, they are found within several complex structural blocks (Figure 026.2) and consist entirely of fine-grained, massive, uniform dacite/rhyodacite, and dacite/rhyodacite schist containing up to 1% quartz eyes. Internal stratigraphy, breccia units, pillows, amygdules, and other primary volcanic features are absent. Observed contact relationships with ultramafic volcanic rocks, which flank and are structurally intercalated with the units, indicate the units dip shallowly (5 to 40°) northwest, conformable with bedding in the iron formation. Texturally, these rocks are indistinguishable from the fine-grained calc-alkalic mafic volcanic rocks but can be distinguished from them by the presence of sericite-rich schists, which make up a large percentage of the dacitic/rhyodacitic unit, and by the absence of primary structures described above.

In the northwest, the intermediate to felsic volcanic rocks occur as a continuous, northeast-trending, steeply dipping unit (Figure 026.2) consisting mainly of dacite schist with minor intercalated units of massive and schistose quartz eye-rich rhyolite (up to 20 m wide), feldspathic wacke (up to 15 cm wide) and deep green, rusty weathering chlorite schist (up to 30 cm wide). Near the northern contact with serpentinized ultramafics, iron formation lenses, described below, are structurally intercalated with the dacite schist.

Iron Formation (IF)

Iron formation is a relatively abundant rock type in the southern part of the map area where it shows complex structural relationships with surrounding lithologies (Figure 026.2). To the north, it makes up a very minor component (<1%).

Most of the individual units exposed to the southeast (Figure 026.2) are not continuous along strike, are of variable apparent thickness (<25 to 150 m), and occur in a structurally repeated sequence with ultramafic flows. These units show variable trends, from east-southeast to north-northeast, but bedding dominantly dips shallowly (5 to 40°) north to northwest.

In the southwestern part of the map area, a single iron formation unit is exposed which contains bedding that trends dominantly east-northeast to northeast, and dips shallowly (5 to 40°) to the northwest.

The most common type of iron formation is well-bedded chert with magnetite-poor, argillite interbeds. Less common types, in decreasing order of abundance, include: banded chert-magnetite iron formation; massive bedded siliciclastics; thinly bedded, sugary textured siliciclastics; and massive, red, cherty siliciclastics.

Iron formation exposed in the northern part of the map area occurs as a series of northeast-trending, vertically dipping lenses up to 3 m wide within a 100 to 200 m wide unit of dacite schist (Figure 026.2). The lenses are quartz- and pyrite-rich and are, on average, less than 5 m in strike length.

Shale, Siltstone and Wacke

This lithology occurs as a northeast-trending, northwest dipping, unit north of Bob's Lake which is truncated to the southwest by the Destor-Porcupine Fault (Figure 026.2). The unit consists of thinly interbedded shale, siltstone, and feldspathic wacke with local grading in the feldspathic wacke beds indicating the unit faces northwest. This unit is equivalent to the Whitney Formation of the Porcupine Group of Lorsong (1975) or the "Older" Metasediments of Hodgson (1983a).

Lithic Arenite and Conglomerate

This northeast-trending unit, exposed in the northwest portion of the map area, is equivalent to the Timiskaming Series of Dunbar (1948) and Hodgson (1983a) or the Three Nations Lake Formation of the Porcupine Group of Lorsong (1975) (Figure 026.2). In the section examined east of Three Nations Lake, the formation consists entirely of well-bedded intercalated conglomerate and feldspathic wackes displaying abundant large-scale cross stratification showing consistent south-facing directions, indicating the unit is overturned to the north.

Peridotite Intrusions

Rocks interpreted to be ultramafic intrusions occur in several locations in the map area which have been shown by Pyke (1982) to be mainly peridotitic (dunite) in composition. To the south of Porcupine Lake, massive, medium-grained peridotite occurs as a northeast-trending unit roughly concordant with local lithological trends. This intrusion is partially to completely altered to serpentine + magnetite, but with primary textures well preserved, and is typically a very brittle, competent unit, which does not show evidence of penetrative deformation. Contacts with the surrounding schists were not observed.

Units of peridotite which occur in the south-central portion of the map area are structurally complex (Figure 026.2), are dominantly altered to talc-magnesite, and locally display well-developed foliations and total destruction of primary textures.

Granodiorite

Granodiorite intrusions exposed in the map area are described in detail by Pyke (1982). They include small elliptical stocks and elongate bodies which are co-extensive with interpreted faults, and may contain enclaves of the surrounding country rock (Figure 026.2). These intrusions do not show the effects of penetrative deformation except for the intrusion east of Porcupine Lake, which displays intensely foliated zones within its northern portions.

Quartz-feldspar Porphyry

Several narrow dikes, or sill-like porphyritic units, interpreted to be intrusive in origin, occur within the felsic and ultramafic volcanic sequence in the map area. The units trend from parallel to subparallel with local foliation trends. They consist of 30 to 50% quartz and plagioclase phenocrysts within a fine-grained matrix of quartz, plagioclase, biotite, sericite, and pyrite.

Diabase Dikes

Olivine and quartz-rich diabase dikes occur in the study area. These have been described in detail by Pyke (1982).

STRUCTURAL GEOLOGY

The distribution of lithologies show on Map 2455 of Pyke (1982), Figure 026.2, and described above, suggests a complex structural history for the map area. The interpretation of a complex system of north to northeast-trending faults and splays, shown in Figure 026.2, is favoured in order to explain the distribution of lithologies, the truncation of lithological units and the repetition of lithological sequences observed in the southern part of the map area. These faults are dominantly parallel or subparallel with lithologic contacts, and are commonly coincident with shear zones (up to 50 m wide).

Foliation and Lineations

The most widespread foliation, referred to as S_1 in this study, is a schistose fabric or spaced cleavage trending parallel to subparallel with with lithological trends described above (Figure 026.2). This fabric ranges from weak to intense in the various units and the shallow dips produce schistose domains of large apparent width which form sub-units within the volcanic lithologies. Variations in the orientation of S_1, such as shallow southeast dips or northwest strikes (Figure 026.2), retain the parallel relationship with lithologies and are interpreted to be the result of superimposed deformation. The S_1 foliation steepens (70 to 80°) and becomes more pervasively and intensely developed along shear zones described below (e.g. the Destor-Porcupine Fault).

A second foliation, referred to as S_2, occurs as a widely distributed crenulation cleavage, and as an axial planar cleavage to (F_2) folds in schistose volcanic units. The S_2 foliation is best developed within the shear zones and strikes dominantly northeast, parallel with S_1, and dips shallowly or moderately northwest to locally southeast. Variations in S_2 were observed (i.e. northwest strikes and northeast dips) which maintain consistent relationships with S_1 and they were also interpreted to represent superimposed deformation.

Several lineations were recognized on foliation surfaces. The most widespread lineation, interpreted as L_2, is a shallowly to moderately (5 to 40°) north-northeast plunging, stretching lineation, defined by elongate amygdules in the mafic volcanic rocks, and a mineral streaking along (S_1) foliation surfaces in the various schist units. This lineation shows a variation (northeast to north to northwest) which reflects the variation in trend of the S_1 foliation. In the northern part of the map area, well-developed, shallow to steeply north-plunging, stretching lineations occur along the shear zones.

A second lineation, L_2, is defined by the intersection of S_1 and S_2, or S_2 and bedding, and consistently plunges shallowly to moderately (0 to 50°) east to northeast.

Faults, Shear Zones and Folds

Shear zones can be distinguished from the broad regional deformation by the intense development of foliation and complexly deformed fabrics in the former, described above. The most well-defined shear zone in the map area corresponds with the fault (shown in Figure 026.2) that extends into Tisdale Township, south of Porcupine Lake. Deformation in this zone is best developed within carbonatized ultramafics and within the dacitic/rhyodacitic schists. Based on the consistent, shallow, north to northwest dips of bedding in the iron formation and foliation in the carbonatized ultramafics and dacitic/rhyodacitic units, this fault, and others, is interpreted to dip shallowly north to northwest.

In the immediate hangingwall or footwall of the faults, schistosity (S_1) and/or bedding is deformed into shallow (0 to 50°) northeast plunging folds (F_2). The folds range from open, north to locally south, inclined structures (Photos 026.1a and 026.1b), to isoclinal, north-overturned to recumbent structures (Photo 026.1c). The observed folds are of centimetre or metre scale and locally show evidence of gentle refolding (dome and basin patterns) along northwest-trending axes.

The consistent shallow plunges of fold axes (L_2) that trend subparallel to trends of interpreted faults, and consistent north plunges of stretching lineations along fault zones, described above, suggests the faults are dip-slip structures. The direction of motion along the faults is not firmly established because of the lack of reliable kinematic indicators, but the presence of foliation, locally deformed into shallow plunging, north-dipping, "Z"-shaped kink folds along the shear zones, (Photo 026.1d) suggest they are north-side up thrust faults. Additional supportive empirical evidence for this interpretation is the observation that the faults are locally coincident with linear zones of intensely developed foliation which indicates crustal shortening, an environment favourable for thrust faults, rather than crustal extension, an environment favourable for normal faults.

ECONOMIC POTENTIAL OF SOUTH WHITNEY TOWNSHIP

Although significant gold deposits have not been discovered south of the Destor-Porcupine Fault, minor amounts of gold have been extracted or delineated in deposits in Cody Township immediately east of Whitney Township (Goldhawk Mine, Porcupine Peninsular Mine, Aquarius Deposit (Leahy 1971)), in Shaw Township (Carshaw Deposit (Fyon 1983)), and in Deloro Township. In Cody Township, the deposits are hosted by a variety of lithological types, including carbonatized ultramafics (Aquarius Deposit) and fall

Photo 026.1a. *Upright, asymmetrical open fold developed in chert beds within unit 1F (looking east).*

Photo 026.1b. *North-inclined, asymmetrical, open fold developed in schistose ultramafic volcanic rocks (looking east).*

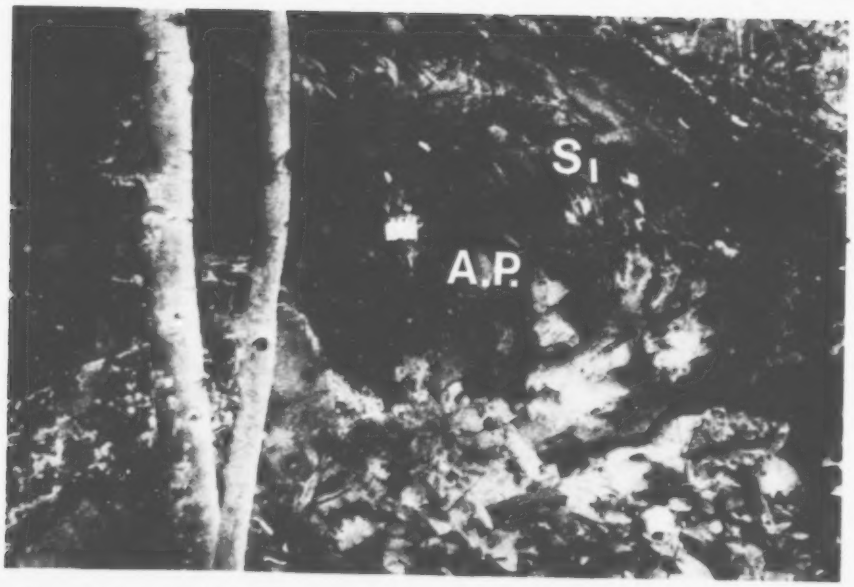


Photo 026.1c. *Recumbent, near isoclinal fold structure developed in dacitic schist (looking northeast). A.P.- axial plane of fold; S_1-foliation.*

Photo 026.1d. *Asymmetrical shallow plunging, "Z"-shaped kink bands developed in dacitic schist with near vertical, axial planar, spaced cleavage (looking northeast at vertical face).*

along a system of northeast-trending faults (Map 2222 of Leahy 1971), many of which can be traced into Whitney Township. In view of these deposits, and the criteria which is used to assess the potential for gold mineralization in the Porcupine Camp, the area which shows the highest potential for gold mineralization in the map area corresponds to the northeast-trending fault, (shown on Figure 026.2, and described above) which occurs south of Porcupine Lake and extends into Tisdale Township. The extent of this structure eastward is not known but it appears to be equivalent with the fault system described by Leahy (1971) in Cody Township. There has not been any recorded or visible signs of past exploration along this structure.

In addition to gold, there is potential for open-pit talc-magnesite mines coming into production (Allerston's North and South Zones) if supply and demand market conditions become favourable.

CONCLUSIONS

The geology of South Whitney Township consists of two structural domains separated by a northeast-trending fault interpreted as a thrust fault. The southern domain consists of a shallow-dipping sequence of IF, mafic/ultramafic and intermediate/felsic volcanic rocks which have been structurally thickened by recumbent isoclinal folding and faults subparallel to bedding. These faults are also interpreted as thrust faults. The northern domain consists of a steeply dipping sequence of intercalated intermediate/felsic volcanic rocks and turbiditic sediments. This domain is in turn truncated to the west by the Destor-Porcupine Fault. This newly defined fault, which separates the two structural domains, is interpreted as a splay of the Destor-Porcupine Fault and is coincident with a zone (50 to 100 m wide) of intense deformation, hydrothermal alteration, quartz veining and quartz porphyry, and granodiorite intrusions. The zone has not been previously tested for gold mineralization and appears to be related to a fault system which hosts gold deposits in Cody Township.

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027. Geology of the Lower Detour-Hopper-Sunday Lakes Area, Northeastern Ontario

Soussan Marmont

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Field work during the summer of 1987 consisted of detailed mapping of the Lower Detour-Hopper-Sunday Lakes area, situated in Northeastern Ontario, immediately west of the Quebec-Ontario provincial border (Location Map). The project, presently in its third year, started with a detailed study of the Detour Lake Mine (Marmont 1984, 1986) and continued to encompass the regional setting of the deposit (Marmont 1985). The present study was initiated to provide information on the geology of the entire belt, in order to better define the regional setting of the Detour Lake Mine and to identify other areas of economic potential.

The map area extends over some 440 km^2, from 49°52'30"N Latitude and 79°30'00"W Longitude to 50°05'00"N Latitude and 79°52'30"W Longitude. The only road access to the area is via a 200 km long gravel road to the mine site from Cochrane or Iroquois Falls, which for the most part bypasses the greenstone belt. Therefore, access to most of the map area can only be achieved by fly camping in several locations.

PREVIOUS WORK AND EXPLORATION ACTIVITIES

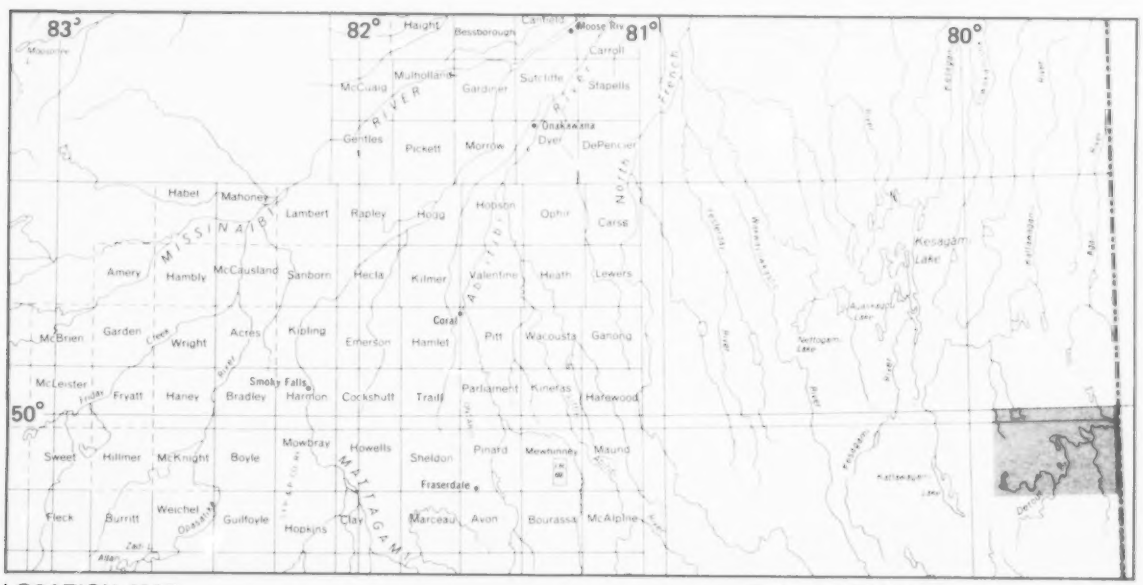
The only published geology maps of the area are a preliminary map and a 1:100 000 map (Johns 1982), which were constructed primarily on the basis of geophysical interpretations, compilation of property maps and drill logs submitted by exploration companies as assessment file reports, and limited outcrop hopping by helicopter. During the present survey, many new areas of outcrop were found and most suboutcrops were exposed. Also, core from exploration projects of many companies was re-logged; as a result, the regional geology of the area is revised and better defined, and additional structural data is provided.

Exploration in the Detour-Hopper-Sunday Lakes belt has been quite limited. Unlike the main part of the Abitibi greenstone belt and other greenstone terrains throughout Ontario, which have been extensively prospected and explored, inaccessibility of the area, combined with a thick overburden cover, deterred prospecting of the region in the first few decades of this century. Prior to the discovery of the Detour Lake orebody by Amoco Canada Petroleum Company Limited in 1974, no exploration activity is recorded. Since then, sporadic exploration by various companies has taken place; however, so far none has led to a new discovery (Assessment Files Research Office, Ontario Geological Survey, Toronto).

Numerous prospective exploration targets are currently being examined by various companies on the eastern (Quebec) extension of the belt.

GENERAL GEOLOGY

Average exposure in the area is approximately 5 to 6%; in particular, the eastern segment of the belt is entirely overburden covered. Hence, the scale of mapping is dictated by outcrop availability; in areas of good exposure, the scale is 1 inch to 1/4 mile or more detailed; however, there are major blank spaces between clusters of exposures. For this reason, caution has been exercised in interpretation of belt-wide stratigraphic and structural continuities.



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

SUPRACRUSTAL ROCKS

One of the most prominent features of the belt is the predominance of mafic rocks. Together with gabbroic and dioritic intrusions, massive and pillowed flows of tholeiitic basaltic composition constitute the largest volume (more than 90%) of the lithologies. The basaltic flows consist of fine-grained to aphanitic amphibolites, which occasionally are feldspar-phyric and amygdaloidal. Pillowed flows often contain hyaloclastic or cherty/sulphidic pillow interstices; under amphibolite grade metamorphism, the pillow selvages have been transformed into an assemblage of garnet-chlorite-epidote-quartz. In the area north of Detour Lake (Figure 027.1), ferruginous and sulphidic mafic metavolcanics are abundant. In the area between Lower Detour and Detour Lakes, several outcrops of flow breccia and massive mafic flows with felsic pods are interspersed with the massive and pillowed flows.

Mafic to intermediate intrusions occur as dikes and plugs throughout the area. In most instances, distinction between coarse-grained flows and gabbroic sills is not easily achieved. The most extensive mafic intrusions are the gabbro-diorite-quartz diorite body on the southwestern shore of Lower Detour Lake, the gabbro-pegmatite-diorite intrusion northeast of the Detour Lake Mine (herein named the East Lake gabbro), and a gabbro-diorite body surrounding Detour Lake (Figure 027.1). All of these intrusions crosscut the mafic metavolcanics and may have been feeders to the flows. The density of dikes is distinctly increased in the vicinity of these intrusive bodies; this is most noticeable in the northeastern part of Detour Lake, and west of Lower Detour Lake.

Felsic to intermediate intrusions occur occasionally as dikes throughout the area and as a small trondhjemite body northeast of the Detour Lake Mine. The felsic dikes comprise various feldspar and/or amphibole porphyries, trondhjemite, granodiorite, monzonite, and aplite/pegmatite. It may be significant to point out that intrabelt felsic stocks and plugs are rare in the Detour-Hopper-Sunday Lakes belt, in comparison to the central core of the Abitibi belt, where numerous, late Archean, calc alkalic and alkalic, felsic intrusions are present.

Ultramafic rocks are absent from most of the map area and have been encountered in only a few isolated outcrops (Figure 027.1). Within the Detour Lake Deformation Zone, a chlorite-actinolite-carbonate-talc schist occurs as lensoidal slices (Marmont 1986). This unit may represent either komatiitic flows or ultramafic intrusions emplaced along the shear zone; in the absence of intrusive textures and stratigraphic contacts, its origin is uncertain. Approximately two miles north of the Mine and east of Friday Lake, a coarse-grained rock, consisting of more than 90% hornblende (most probably pseudomorphing clinopyroxene), occurs in two small outcrops. These amphibolites (previously pyroxenites) are part of the East Lake gabbro-pegmatitic gabbro pluton. A medium-grained amphibolite, consisting of more than 95% ferromagnesian minerals, occurs in the area southwest of Sagimeo Lake. Where it is fractured, this amphibolite has been altered to serpentine.

Felsic volcanic rocks have only been found in two small outcrops, on the Quebec border, at Latitude 49°55'30"N, and southwest of Sunday Lake. They consist of very fine grained to aphanitic quartz-feldspar crystal tuff, with slight carbonate alteration. A 150 lb. sample of the rock at the eastern location was collected for U-Pb zircon dating. To date, no outcrops of rocks representing proximal facies of a felsic domal centre have been found.

The metasediments consist of two distinct lithological packages. To the north and east of Lower Detour Lake, they consist of agglomerates, grits and argillite beds and polymictic conglomerates. In the area east of Friday Lake and southwest of Sunday Lake, however, the metasediments are less heterolithic and primarily consist of chloritic wackes. The latter may be correlative with the compositionally layered metasediments south of the Mine, which have been tectonically segregated into fine-grained bands of quartz-biotite-plagioclase and coarse-grained layers of hornblende-quartz-carbonate (Marmont 1984, 1986). In the area southwest of Sagimeo Lake, a sequence of finely bedded wackes consists of alternating, fine-grained quartzo-feldspathic and chloritic layers. Lack of outcrops in the central part of the belt, where an anticlinally folded sedimentary package had been interpreted by Johns (1982), and differences in both provenance and environment of deposition of the two packages of lithologies, pose problems in correlating the two areas of sediments to the north and south of the belt. Conventional banded chemical sediments have not as yet been found in the belt.

In many respects, the lithological characteristics of the Detour-Hopper-Sunday Lakes area are more analogous to those of the Chibougamau-Matagami greenstone belt (Guha and Chown 1984) rather than the central Abitibi greenstone belt.

METAMORPHISM

Peak metamorphic minerals consist of hornblende and garnet. The metamorphic grade of the rocks is lower amphibolite for the entire map area, with two possible exceptions:

1. a package of pillowed flows to the very northeast of the belt (Quebec border, Latitude 50°05'30"N) where the metamorphic grade may be greenschist. Drill cores examined by the author from the eastern extension of the Detour Lake belt, within Quebec, also were of greenschist facies. This indicates the presence of a metamorphic isograd in the area east of Sunday Lake.
2. adjacent to the contact of a large granitoid complex, east of Hopper Lake, where the metamorphic grade may be in the upper amphibolite range.

Variations in metamorphic grade will be confirmed by determination of the plagioclase compositions, and by thin section studies to determine the presence of other indicator minerals.

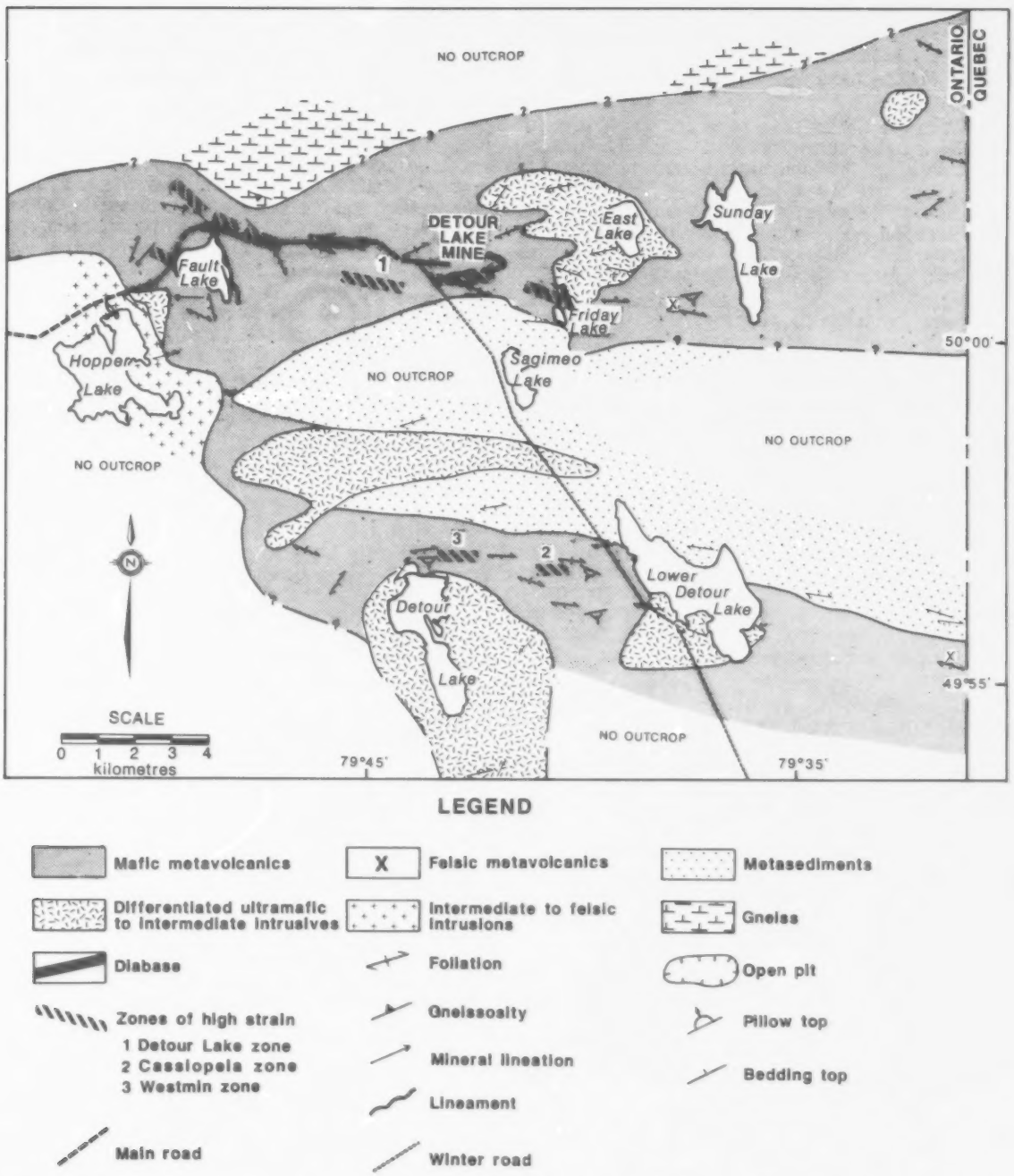


Figure 027.1. *Generalized geology and structure of the Lower Detour-Hopper-Sunday Lakes area.*

STRATIGRAPHY

Top determination from the mafic metavolcanics has been limited. In most instances, the flows are massive and, although there may be more than one flow, lack of adequate outcrop and observed contacts precludes the possibility of distinction between individual flows. In the undeformed pillowed flows, some younging directions have been established, such as in the area between Lower Detour and Detour Lakes, where tops are to the south-southwest.

In contrast to the younging direction of the mafic metavolcanics, the metasediments to the north and west of Lower Detour Lake indicate northerly younging directions. Hence, the package of metavolcanics

to the south and the metasediments north of Lower Detour-Detour Lakes are stratigraphically back to back. Top determinations from pillowed flows southwest of Sunday Lake also indicate a southerly facing direction.

Within the Detour Lake Mine and along strike of the Detour Deformation Zone, stratigraphic correlation is not possible. The chloritic metasediments east of Friday Lake may be locally derived, but, since no contacts with the metavolcanics have been observed, their stratigraphic position is uncertain. Top determinations from pillowed flows southwest of Sunday Lake also indicate a southerly facing direction.

GRANITOIDS AND GNEISSES

The Detour Lake greenstone belt is bounded by a gneissic terrain to the north and the Hopper Lake granitoid complex to the west.

The augen gneiss to the north contains centimetre-long plagioclase eyes and shows a strongly developed gneissosity. The dominant lithology of the Hopper Lake batholith is a massive to weakly foliated, coarse-grained, quartz diorite-quartz monzonite-granodiorite. The border phase of the pluton is a coarse-grained diorite with large, euhedral, glassy, grey, plagioclase crystals rimmed by a chalky, buff-coloured feldspar. Less commonly, feldspar-phyric diorite, monzodiorite and biotitic diorite are in gradational contacts with the main phase. Aplite and pegmatite dikes crosscut all other granitoids.

In contrast to the gneissic domain to the north, the Hopper Lake granitoid complex is relatively undeformed; the only deformation in this rock occurs as discrete, narrow shears, mostly near the margins of the complex. At the eastern contact of the complex with the mafic metavolcanics, minor assimilation of the country rocks was observed, but in general, the batholith was emplaced passively and possibly at a later stage in the development of the greenstone terrain.

STRUCTURAL GEOLOGY

A weakly- to strongly-developed planar fabric is pervasive throughout the entire map area. In general, with few local variations, this foliation has an east to southeasterly trend and vertical to steep dips. In the area of Fault Lake, the foliation trend becomes north-northwesterly, whereas near the eastern margins of the Hopper Lake granitoid complex it strikes northeasterly. In the area northeast of the Detour Lake Mine, the planar fabric of the rocks trends northeasterly but, approaching the Mine, this fabric rotates into the east-southeasterly strike of the Detour Lake Deformation Zone (No. 1, Figure 027.1). Within the mafic rocks, the planar fabric is particularly prominent within the pillowed flows, where the competency contrast between the core of the pillow and the pillow selvage allows better development of the flattening fabric. Major cross structures trending north-northwesterly are best seen in two locations: in the east-central part of the area where a diabase dike trends 150°E to 168°E, and to the west, on the eastern shore of Fault Lake, where the easterly striking foliation is deflected into a north-northwesterly trend. In addition to discrete, narrow shears that occur in the map area, three major zones of intense deformation - the Detour Lake Deformation Zone, the Cassiopeia Zone, and the Westmin Zone - were identified.

The Detour Lake Deformation Zone (No. 1, Figure 027.1), which is predominantly a ductile shear zone, encompasses the Detour Lake Mine. The Mine sequence constitutes some of the most highly strained rocks within this structure and therefore is considered to be the core of the deformation zone. The Detour Lake Deformation Zone has been traced over 15 km to the west, where it abuts against the Hopper Lake granitoid complex, and some 4 km to the east (Friday Lake area), where lack of outcrops precludes further delineation of the zone. The width of this ductile shear zone is a subject of debate; immediately north of the Mine sequence, rocks located more than 2 km from the high strain core are still influenced by the deformation and show discrete zones of intense shearing (Figure 027.2). However, between the Mine sequence and these single shears, there are areas of moderately undeformed rocks. Hence, definition of the deformation zone boundaries is tentative.

The Detour Lake Deformation Zone is characterized by a strong penetrative fabric, which strikes predominantly southeasterly, but rotates into a north-northwesterly trend near the margin of the Hopper Lake granitoid complex. In some outcrops with both horizontal and vertical exposures, the fabric can be defined as linear and pencil-shaped; in these cases the rocks are best termed L-tectonites. In most cases, a tectono-metamorphic layering of the pillowed flows and gabbros generates a finely laminated, "tuffaceous-looking" rock. The ductility contrast, which results from this layering as well as that inherent to felsic to intermediate dikes, gives rise to an anisotropic package of rocks which deform according to their competency; the more brittle units, such as the dikes, cherty pillow selvages and quartz veins, are often boudinaged (Photo 027.1). Where determination is possible, the asymmetry of the boudins indicates a sinistral sense of lateral motion. In most instances, rotation of felsic to intermediate dikes into the foliation also supports a left-lateral movement. The less competent units are asymmetrically folded; these shear folds consist of "M" folds, with "S" and "Z" symmetries on their limbs.

A stretching lineation, consistently plunging moderately to the west, is also a dominant feature of the Detour Lake Deformation Zone.

A zone of ductile deformation, herein called the Cassiopeia Zone (No. 2, Figure 027.1), was discovered during this survey. The surface expression of the zone is some 15 to 20 m wide and less than 100 m long but, due to thick overburden, its actual extent is not known. Figure 027.3 is a detailed sketch map of the most deformed section of these exposures. The Cassiopeia Zone consists of highly strained, coarse-grained, massive and pillowed flows intruded by intermediate dikes. The boundary between the moderately foliated country rocks and strongly sheared equivalents is relatively sharp. A mylonitic zone occurs some 8 to 10 m south of the

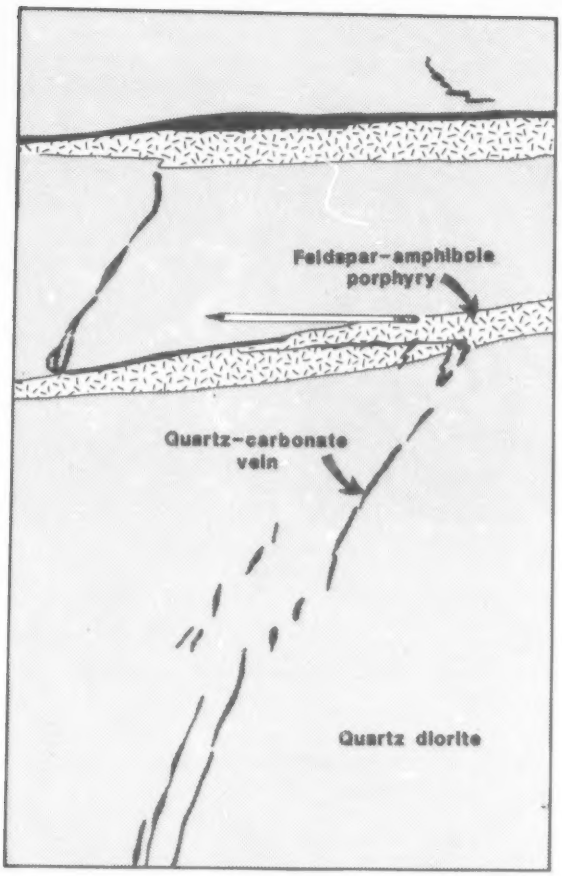


Figure 027.2. "S" shaped shear folded quartz-carbonate vein and attenuated amphibole-feldspar porphyry dike cutting quartz-diorite of the East Lake Gabbro (approximately 1.5 km northeast of the Mine).

northern contact of the shear zone with the undeformed flows. The southern boundary of the shear zone is not exposed. Rusty weathering, some sulphide mineralization, and a few boudinaged quartz veins are associated with the highly strained rocks.

Trenching and removal of the overburden are needed to allow better characterization of the zone and its economic potential.

The third zone of intense shearing, herein called the Westmin Zone (No. 3, Figure 027.1), lies northeast of Detour Lake. The shearing is accompanied by folding and intense silicification. The deformation and alteration style associated with the mafic metavolcanics in this area closely resemble those of the Cassiopeia Zone and it, in fact, may represent a strike extension of the same structure.

ECONOMIC CONSIDERATIONS

To date, with the exception of the Detour Lake Gold Mine, no significant mineralization of base and/or precious metals has been reported from the Ontario side of the belt. Within Quebec, the Selbaie base metal mine is located some 60 km to the southeast of the Detour Lake Mine.

In the area north-northeast of Detour Lake and west of Lower Detour Lake, some trenching has been done on ferruginous mafic flows, but no anomalous values are mentioned in assessment file reports.

The following observations are pertinent to the evaluation of the area for its gold mineralization potential:

1. One of the outstanding features of the mapped area is that the supracrustal rocks are dominantly mafic and homogeneous. In contrast, the Detour Lake Mine area displays a distinct heterogeneity of lithologies. In the few square kilometres that surround the Detour Lake gold mineralization, various lithologies of mafic metavolcanics, a suite of differentiated ultramafic to sodic felsic intrusions, potassic intermediate to felsic intrusions including various porphyries, and metasediments are present. Such inherent crustal anisotropy normally provides favourable conditions for perpetuation of shearing, should the right structural environment prevail. Therefore, at a reconnaissance scale of operation, heterogeneity of the supracrustal package may be a meaningful indicator.
2. There is a general consensus that, throughout the Canadian Shield, a strong correlation exists between Archean lode gold mineralization and major deformation zones (Macdonald 1986; Colvine *et al.* 1984). Hence, shearing and generation of tectonic permeability of this anisotropic package of rocks is a prerequisite for hydrothermal activity. Within the Detour Lake Deformation Zone, the most significant economic feature, is that, although the structure is a zone of strong ductile strain, the gold mineralization at the Detour Lake Mine is entirely fracture- and vein-controlled. In this respect, along the strike length of the structure, the style of deformation of the mine sequence is anomalous in that brittle failure, synchronous with hydrothermal activity and brecciation, prevailed. It is proposed that the brittle deformation was a result of hydraulic fracturing induced by high pressure mineralizing fluids. Hence, a second exploration criterion, which applies on a more detailed scale, may be zones of intense fracturing, brecciation, emplacement of intrusions, and alteration along a major ductile structure.

To date, other areas of brittle deformation similar to that at the Detour Lake Mine have not been seen on surface exposures. However, drilling by Amoco Canada Petroleum Company Limited, along the strike of the structure, has intersected some veining and alteration.

The Cassiopeia and Westmin Zones warrant investigation. The structural features observed in these areas are indicative of a ductile/brittle deformation zone; if enough veining and sulphidation are found in the subsurface bedrock (after removal of the overburden), drilling of the zones is recommended.

Photo 027.1. *Tectonic layering of pillowed flows with boudinaged quartz-garnet-carbonate layers.*

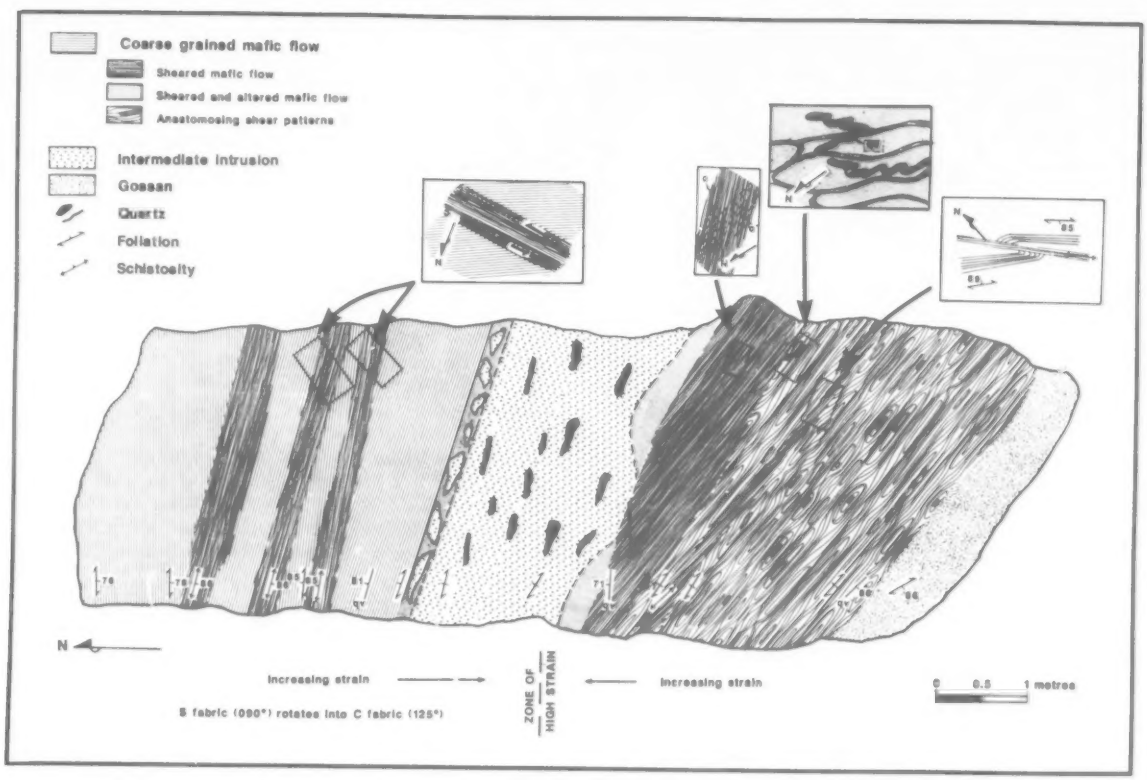


Figure 027.3. *Detailed outcrop map of the most deformed section of Cassiopeia Zone.*

Economic potential for platinum group elements should also be tested by exploration for sulphide-bearing parts of the differentiated gabbroic/pegmatitic complexes, specifically the East Lake gabbro body northeast of the Detour Lake Mine.

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028. Black River-Matheson Economic Geologist Program

A.C. Bath

Economic Geologist, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kirkland Lake.

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INTRODUCTION

The position of Economic Geologist in the office of the Resident Geologist, Ontario Ministry of Northern Development and Mines, Kirkland Lake, was established as part of Operation Black River-Matheson (BRIM), a multi-disciplinary geoscience program focused on a forty township block located between Night Hawk Lake and the Québec-Ontario border (Figure 028.1). The Economic Geologist encourages exploration activity at the local level by being available to all members of the exploration community as a source of exploration-related information and advice. Efforts of the Economic Geologist are directed toward promoting the BRIM area, catalyzing the property optioning process, interfacing between the public and the private sectors and, in general, providing services which facilitate exploration. Specifically, the Economic Geologist is available to:

1. assist local prospectors with property visits, assessment files searches and advice
2. document new mineral occurrences
3. revise and enhance descriptions of previously documented mineral occurrences
4. compile relevant exploration data
5. orient explorationists unfamiliar with the area

Most of the 1987 field season was spent examining mineral showings within the BRIM area: nineteen showings were visited. This summary contains brief descriptions of four of these properties; their locations are given on Figure 028.1. Descriptions of the other properties visited will appear in a later publication.

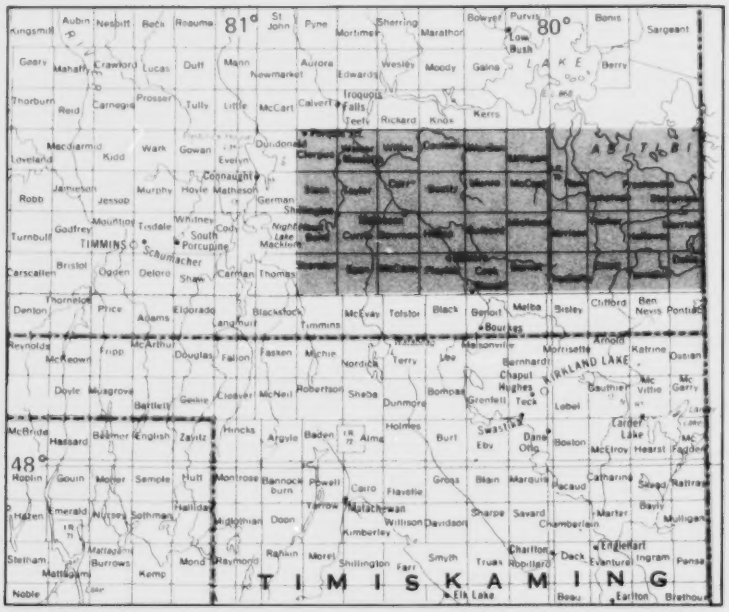
The Geological Data Inventory File (GDIF) component of Operation Black River-Matheson was completed during 1987. Figure 028.2 is an updated version of the BRIM area GDIF status map, current through September, 1987. Completed, but as yet unpublished, GDIFs are expected to be available in the very near future.

PROPERTY DESCRIPTIONS

TALISMAN GOLD MINES LIMITED PROSPECT

The uncapped shaft and old surface trenches on this property are largely confined to patented claim 8289, in the northwest quarter of the southern half of lot 7, concession VI, northwestern Guibord Township, about 150 m south of Highway 101. Prior to 1935, Talisman Gold Mines Limited and previous operators sank a 33 m deep, 2-compartment, vertical shaft and completed about 396 m of lateral work on 4 levels, about 10 m of raising on 2 levels and approximately 610 m of surface trenching.

All development and exploration work performed on the property appears to have been concentrated



LOCATION MAP Scale : 1 : 1 548 000 or 1 inch to 25 miles

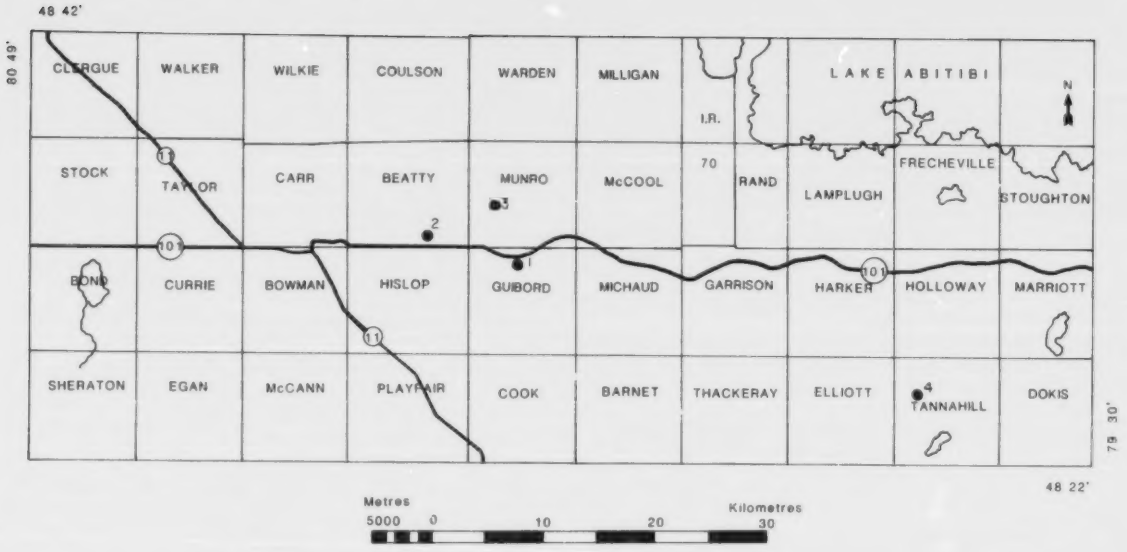
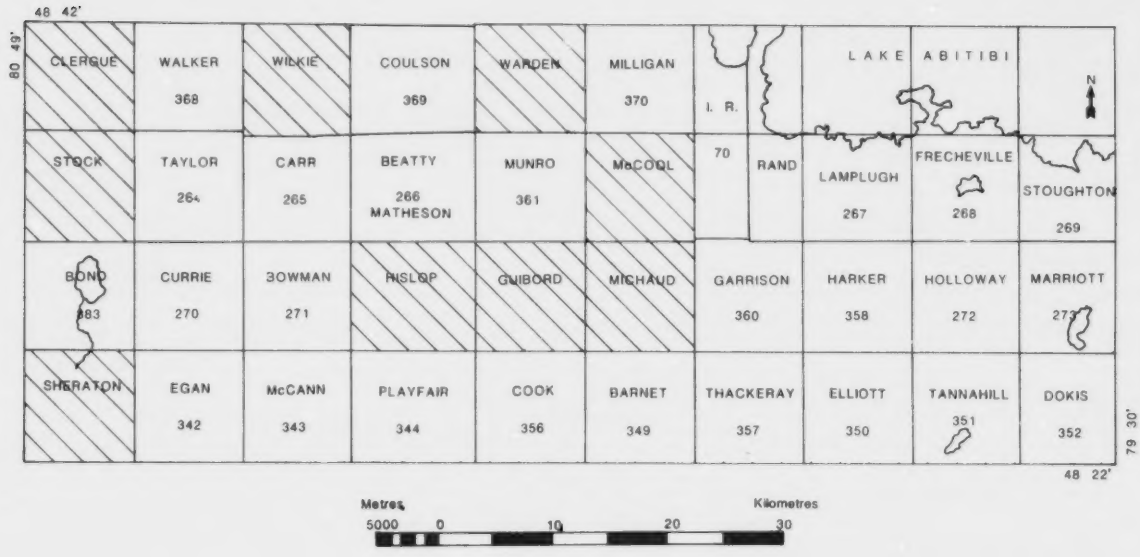


Figure 028.1. *BRIM area, showing locations of properties described. 1 - Talisman Gold Mines Limited Prospect, 2 - Beatty Syndicate Prospect, 3 - Lalonde Prospect, 4 - Gagne/St. Amant Prospect.*



GEOLOGICAL DATA INVENTORY FOLIO (GDIF) STATUS

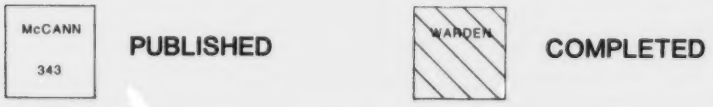


Figure 028.2. *Status of GDIF's for the BRIM area as of September 1987.*

on quartz-carbonate veins and vein systems which, when explored underground, proved to be discontinuous at depth. Precious metal mineralization, as free gold and gold associated with pyrite, chalcopyrite, tetrahedrite and tellurides in carbonatized and sericitized wall rocks, is reported to be associated with these veins. A "small quantity" of dump material is reported to have averaged about 0.40 ounce gold per ton, and a 2-ton bulk sample is reported to have yielded 2.2 ounces of gold (Assessment Files, Resident Geologist's Files, Ontario Ministry of Northern Development and Mines, Kirkland Lake).

The old workings are located in subgreenschist facies, medial to distal, turbiditic sediments of the Archean Porcupine Group on the generally northeast-facing, southwest limb of the McCool Hill Syncline, the dominant structural element in this part of the McCool-Guibord Township area north of the Porcupine-Destor Fault Zone (Johnstone and Trowell 1985a, b). Bedrock exposure is limited to the immediate area of the old workings, mostly in the southern half of claim 8289. Here, the metasediments, which strike 095° to 105°, are yellow-green (sericitized) and rusty weathering (dolomitized) interbedded siltstones, feldspathic wackes, and rare, polymictic conglomerates. Mine plans indicate that the sediments dip steeply north (Assessment Files, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kirkland Lake).

Dolomitized lamprophyre dikes, ranging from 1.2 to 3.6 m in thickness and with various orientations, intrude the metasediments in the area of the old workings (Prest 1953). Northeast of the showing, several north-trending Matachewan (Archean) diabase dikes are exposed. A recent airborne electromagnetic survey over Guibord Township identified a north-trending, magnetic ridge centred a short distance west of the showing; this suggests that an unexposed, near-surface Matachewan dike, or dikes, may occur at this location (OGS 1984a).

A strongly developed foliation, trending subparallel to bedding (095° to 100°) and dipping steeply to the south, is present as a sericitic foliation in the metasediments and as an alignment of platy biotite or phlogopite in the dolomitized lamprophyre dikes. Most of the trenches, which exposed quartz-dolomite veins, trend 050° to 070° and cut, obliquely, the well-developed foliation (Assessment Files, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kirkland Lake).

All surface trenches and pits were overgrown and detritus-filled and/or flooded, when visited in June, 1987. Well-mineralized grab samples were obtained from a large rock dump adjacent to the old shaft and submitted for assay to Swastika Laboratories Limited, Swastika. Four of these samples returned anomalous gold (210 to 700 ppb) and silver (1.7 to 28 ppm) values and uniformly low copper (<68 ppm), lead (<38 ppm) and arsenic (<28 ppm) values.

All samples from the property consisted of quartz-dolomite veinlets or dolomite-filled fractures in pervasively dolomitized wackes and conglomerates, and sericitized siltstones. Pyrite constitutes 3 to 7 percent of individual samples. In altered wackes, pyrite most commonly occurs as fine-grained disseminations marginal to quartz-dolomite veins, or as a fracture-controlled, fine-grained, pyrite-dolomite assemblage cutting the foliation at a high angle. One sample consisted of a well-foliated, sheared, fine-grained, pyritic, sericitized and dolomitized siltstone devoid of vein material. This sample was among the least anomalous in silver (1.7 ppm) of all samples. One sample, consisting of a quartz-dolomite-galena veinlet cutting pervasively dolomitized and sericitized wacke, contained anomalous gold (2000 ppb), silver (4.7 ppm), lead (1010 ppb) and zinc (1999 ppm). Galena was not previously noted to occur on the property.

BEATTY SYNDICATE

The shaft area is located on a prominent outcrop in the southwestern corner of claim 700896, in the southeastern quarter of the southern half of lot 5, concession II, Beatty Township. The best access is provided from the west along a 2.2 km, all terrain vehicle-passable trail cut along the line between concessions I and II. The trail begins about 120 m north of the gravel road located between lots 7 and 8 in concession I, Beatty Township, along its overgrown extension. The gravel road meets Highway 101 at the apex of the Froome Lake bend.

From 1913 to 1919, claims in the area were staked, prospected and pitted. During this period, a 1.5 m by 2 m, 8 m deep, inclined shaft is reported to have been sunk on a quartz vein in carbonatized and sericitized sediments (Assessment Files, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kirkland Lake). In 1949, a grab sample of vein material from the showing is reported to have assayed 0.09 ounce gold per ton (Satterly and Armstrong 1949). During 1981, Amax Minerals Exploration (now Canamax Resources Incorporated) performed a reconnaissance scale geological survey over a large group of claims which included the shaft area. Follow-up exploration work was recommended, but not carried out. In 1984, Maude Lake Gold Mines Limited, as part of an exploration program covering a larger group of claims in the south central part of Beatty Township, performed geological and ground vertical component magnetic, radiometric and two very low frequency electromagnetic surveys which included the shaft area. A grab sample of vein material taken from the shaft area during this program is reported to have assayed 0.018 ounce gold per ton (Assessment Files, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kirkland Lake).

The showing is hosted by north-facing and generally over-turned, south-dipping, subgreenschist facies, medial to distal, turbiditic wackes and siltstones of the Porcupine Group. Wackes are characteristically grey, occur in beds several centimetres to several metres thick, and contain pinhead-size, rounded to subangular, quartz grains. Siltstones are usually slate grey, occur as finely laminated to massive beds up to several decimetres thick, and are intercalated with the wackes in variable proportions. Laminated chert and intraformational conglomerate horizons within the Porcupine Group have also been noted in the area

(Satterly and Armstrong 1949; Assessment Files, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kirkland Lake).

Intrusive rocks in the vicinity of the showing include:

1) felsic bodies intruding the sediments (the closest such body is located about 1600 m east of the shaft area)
2) a northeast-trending, Proterozoic, Abitibi quartz-diabase dike, that is exposed about 60 m northeast of the shaft area
3) a narrow (approximately 60 m), west-northwest-trending, dioritic, sill-like body, that intrudes the sediments about 170 m southwest of the shaft area
4) generally north-trending, Archean, Matachewan diabase dikes, several of which are exposed immediately west of the shaft area
5) small lamprophyre dikes at all orientations to local stratigraphy (Satterly and Armstrong 1949)

The shaft is about 1500 m southwest of the west-northwest-trending Contact Fault, which separates steeply dipping, north-facing, tholeiitic basalts of the Stoughton-Roquemaure Group to the north from the sedimentary rocks of the Porcupine Group to the south. Several north-northeast-trending cross faults, with horizontal displacements of about 100 m, have been identified southeast of the outcrop area, where the sediments are well exposed. In this area, detailed mapping has also identified two stages of deformation, both of which postdate the intrusion of the felsic bodies (Johnstone and Trowell 1985a; Assessment Files, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kirkland Lake).

A recent airborne electromagnetic survey over Beatty Township failed to identify any significant bedrock conductors in the shaft area (OGS 1984b).

Old development work in the shaft area consists of a 50 m long, discontinuous trench trending 068° in a 1 to 2 m wide shear zone developed in interbedded wackes and siltstones on both sides of the flooded, 5 by 3.5 by 8 m deep, uncapped, inclined shaft. The trench is now largely detritus-filled; the shaft plunges at about 65°, at a bearing of 338°.

The wackes are grey, fine grained, and contain abundant, pinhead-size, rounded quartz grains. Interbedded with the wackes are narrow (generally <10 cm), grey siltstone and cherty siltstone beds. The sediments strike 122° and dip 70°SE. Graded bedding in the silty interbeds consistently fines to the northeast, indicating that the rocks are overturned. A well developed fracture cleavage, trending 065° to 080° and dipping about 65°N, subparallel to the shear zone, is present in the outcrop near the shaft.

The discontinuous quartz vein on which the shaft was sunk is exposed intermittently in the detritus-filled trench and is visible in the shaft walls. It is apparently confined to the shear zone, and consists of 1 to 10 cm thick, blue-grey quartz/actinolite stringers and pods hosted by rusty weathering, sheared, dolomitized, sericitized, silicified and mildly sulphidized sediments. Trenching northeast of the shaft presumably follows the shear zone as far as the northeastern edge of the outcrop, but the trench is detritus-filled here and the shear zone is not visible. Southwest of the shaft, the shear zone is exposed in a 25-m long trench that extends as far as the southeast edge of the outcrop, where it is lost under overburden. About 30 m along strike to the southwest, shearing is weakly developed in an outcrop of sediments, and is cut by a north-trending Matachewan diabase dike.

Muck samples from the waste dump near the shaft indicate that the quartz veins are hosted by sheared and pervasively dolomitized, sericitized and silicified sedimentary rocks, which have been subsequently brittly fractured, and non-pervasively carbonatized (calcite). Sulphide mineralization observed in dump grab samples consists of very fine-grained, disseminated pyrite, pyrrhotite and very rare chalcopyrite which in aggregate rarely exceed 4 percent in any single hand sample. Sulphide minerals occur both within and marginal to quartz-actinolite vein material in the sheared and altered sediments. Sulphide minerals were only rarely observed in hairline fractures cutting primary laminations.

All samples assayed as part of this program were dump grab samples, except for one chip sample taken across the trench about 3 m southwest of the shaft. All assayed samples which contained quartz (with or without actinolite) vein material returned highly anomalous gold values, ranging from 3100 to 8500 ppb. Samples devoid of vein material returned values ranging from nil to 450 ppb gold. One sample of unaltered wacke, taken in the vicinity of the Matachewan diabase dike about 65 m west of the shaft, returned 30 ppb gold. Silver (<70 ppb), zinc (<50 ppm) and arsenic (<120 ppm) values all were uniformly low, regardless of whether or not vein material was present in the sample.

The auriferous quartz veins are hosted by a narrow zone of ductile shear in turbiditic metasediments. Alteration associated with the shear zone is confined to it and consists of pervasive dolomitization, sericitization, silicification and weak sulphidization. Although alteration effects and gold mineralization appear to be confined to the shear zone, a well-developed, subparallel fracture cleavage in the surrounding metasediments may assist in locating other shear zones that may exist in the area. The showing is notable for the subtlety of its sulphide mineralization and for the consistently highly anomalous gold values associated with quartz vein material. Also noteworthy is the presence of the Abitibi quartz diabase dike which crops out northeast of the shaft. A ground magnetic survey conducted over the property clearly indicates that this dike continues to the southwest in subcrop, subparallel to the mineralized shear zone, and is present a few tens of metres north of the shaft (Assessment Files, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kirkland Lake). The relationship between this dike and the northwest-dipping shear zone immediately to the south has not been established.

LALONDE PROSPECT

The Lalonde Prospect is located in the northeast central part of claim 848455, in the northeastern quarter of the southern half of lot 10, concession III, Munro Township.

In 1987, D. Lalonde of Timmins stripped, trenched and sampled bedrock in the area, after ground magnetometer and very low frequency electromagnetic surveys were conducted. Most of the stripping and sampling was concentrated in claim 848455, where numerous assays greater than 0.01 ounce gold per ton and several assays greater than 0.40 ounce gold per ton had been reported (Assessment Files, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kirkland Lake). The property is currently being explored by Canamax Resources Incorporated.

The showing, which is immediately north of the southeast-trending Munro Fault Zone, is underlain by tholeiitic basalts of the Stoughton-Roquemaure Group. A laterally persistent, east-southeast-trending anticline trends across this part of the property immediately south of the showing. Although not mapped in the immediate area of the showing, faults at high angles to the anticlinal axis and with apparent horizontal displacements of about 100 m are present to the northwest. Intrusive rocks in the immediate vicinity of the showing are north-trending Matachewan diabase dikes (Johnstone and Trowell 1985a).

A recent airborne electromagnetic survey over Munro Township did not identify any significant bedrock conductors in the area (OGS 1984c). This survey does, however, indicate that the area straddles the northern flank of a prominent, southeast-trending magnetic valley, which coincides with the location of the Munro Fault Zone (Satterly 1952, Johnstone and Trowell 1987a).

When visited in August 1987, stripping of a rectangular, 60 by 70 m area had exposed a 10 m by 4 m outcrop knob which had been partially blasted. The outcrop consists of rusty weathering, bleached, grey, pervasively dolomitized and weakly foliated, amygdaloidal, pillowed volcanic rocks which are cut by white, quartz-dolomite veins and stringers. Pillow facing directions indicate that tops are to the north. On the southern side of the stripped outcrop, the northern edge of a shear zone is poorly exposed in a shear face. Immediately south of the stripped outcrop, a 30 m long and 4 m wide trench, trending 110°, has been dug in sand. When visited, the trench was flooded, but it appears to be several metres deep and, when drained, would probably provide much better access to the shear zone than that provided by only the stripped outcrop.

Exposed on the stripped outcrop are many quartz-carbonate veins of several generations and attitudes. At least two sets of veins are present, one predating the foliation and one postdating it. Two sets of brittle fractures are developed in the dolomitized volcanic rock; one set trends 110°, parallel to the inferred trend of the shear zone, and dips steeply to the south. The other set trends 070° to 080° and has subvertical to steeply southern dips. Detailed mapping of the outcrop may unravel the relationships between the observed structural features; this was not done during the brief visit.

The shear zone is poorly exposed, but appears to trend 110°. A set of brittle fractures developed in the dolomitized volcanic rocks may indicate that the foliation in the shear zone dips steeply south.

The stripped outcrop of dolomitized lavas is located about 20 m south of a prominent outcrop of north-facing, rusty-weathering, grey, calcite-altered amygdaloidal pillowed lavas. Here, coarse-grained arsenopyrite crystals fill vesicles. Along the southern margin of the prominent outcrop the calcite-altered lavas appear to be in sharp contact with the dolomitized lavas which host the shear zone.

Sulphide mineralization observed in outcrop and in blasted muck fragments consists of pyrite and arsenopyrite, associated with quartz-dolomite, quartz-calcite, and quartz-dolomite-green tourmaline veins and stringers. The sulphide minerals usually occur in dolomitized rock, marginal to the veins, and were only occasionally observed to occur within the veins or as seams cutting the veins. In one instance, a bleb of chalcopyrite and bornite was observed in a quartz-dolomite veinlet.

Many of the blasted muck samples examined consist of fine-grained chlorite schist, with or without vein material. These samples presumably are from the shear zone with which the gold mineralization at the prospect is associated. It may be tentatively inferred that, at least along the northern contact of the shear zone, the mineralized zone is characterized by a zone of ductile shear, represented by chlorite-dolomite schist, which trends 110°. The shear zone appears to be in sharp contact with surrounding weakly-sheared, pervasively dolomitized, pillowed volcanic rocks. The dolomitized volcanic rocks in turn appear to be at least 20 m wide and enclosed by a zone of pervasive calcite alteration distal to the shear zone.

Gold is associated with the disseminated sulphide mineralization. Nine samples of well-mineralized material were assayed and all were highly anomalous in gold (values ranged from 810 to 5490 ppb), contained negligible silver values (the best value was 0.02 ppm), and were uniformly low in copper (all values <90 ppm), lead (all values <110 ppm) and zinc (all values <128 ppm). One sample of the calcite-altered basalt distal to the shear zone returned a lower, but still highly anomalous gold value (480 ppb) and base metal values comparable to those obtained from the well mineralized samples. All samples analyzed were highly anomalous in arsenic (values ranged from 0.05 percent in the sample of calcite-altered basalt to values consistently >0.10 percent in the well-mineralized samples).

Observations from both the outcrop and from the blasted muck samples indicate that the mineralizing process was complex and multistage.

The highly anomalous gold values obtained from the limited outcrop exposure justify further exploration of the prospect area. This should be directed toward:

1) quantifying the size and shape of the auriferous zone, and the distribution and continuity of gold values within it

2) establishing the relationship between the auriferous zone and both regional and local structural and stratigraphic elements, such as the Munro Fault Zone and the east-southeast-trending anticline which has been mapped as traversing the property (Johnstone and Trowell 1985a)

3) determining at what stage in the tectonic-hydrothermal history of the mineralizing event the gold was introduced

4) locating similar deposits, based on the results of the above work

GAGNE/ST. AMANT PROSPECT

The Gagne/St. Amant Prospect is located in Tannahill Township, near the common post of claims 982942, 982943, 982945 and 982946 on the eastern shore of the Magusi River, just north of a small set of rapids, about 2 km on a bearing of 073° from where the river intersects the township boundary.

Access to the prospect is by a 25-minute motor boat ride from the Magusi River access point on the township line. Road access to the river in early September, 1987, was via bush roads from the Harker-Holloway access road. A gravel road, trending northeast from the Harker-Holloway access road some eight kilometres north of the southern boundary of Elliott Township, was followed 1.8 km to a gravel pit. From there, an old drilling road trending north was followed to a recently cut, narrow bush road. This was followed eastward to the Elliott/Tannahill Township boundary, then south along the boundary for about 1.6 km to the Magusi River.

During 1986, T. Miron of Sudbury performed a limited amount of overburden stripping in the vicinity of what is now the common corner of mining claims 982946, 982943, 982942, 982845. A sketch map indicates that a sample from one pit in the stripped area assayed 0.29 ounce gold per ton (Assessment Files, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kirkland Lake). In 1987, an irregular but contiguous block of 44 mining claims in west central Tannahill Township was staked by Ivan Gangé and André St. Amant, both of Kirkland Lake. Work on the property prior to September, 1987, by these owners consisted of a limited amount of hydraulic overburden stripping and bedrock blasting.

Recent geological mapping of the Magusi River area (Jensen 1982) indicates that the property straddles the contact between older, south-facing rocks of the Kinojévis Group to the northwest and younger, south-facing rocks of the Blake River Group to the southeast, on the north limb of the east-west-trending Blake River Synclinorium. Kinojévis Group rocks are magnesium-rich tholeiitic basalts and related extrusive rocks and sediments, whereas Blake River Group rocks include calc-alkalic basalts to andesites and related extrusive and pyroclastic rocks (Jensen 1982). The contact between the two groups is nowhere exposed at surface on the property, and its inferred position, trending about 060° across the north central part of the claim group, is poorly controlled due to sparse outcrop exposure (Jensen 1982).

South of the inferred position of the Kinojévis/Blake River contact on the property, the volcanic sequence has been synclinally folded. The trace of the synclinal axis trends 080° and has been sinistrally offset in two places by cross faults which trend 165°. The more westerly cross fault appears to be of limited extent, with an apparent offset of about 50 m. The more easterly cross fault, however, is of regional scale. Offset on it may be greater than on the other cross fault, but lack of exposure makes estimating offset difficult (Jensen 1982).

A gabbroic/anorthositic intrusive plug is located about 900 m east of the southeast corner of the property and is indicated to extend into it from the east (Jensen 1982). Approximately 90 percent of the property is covered by deep water glacio-lacustrine Quaternary deposits. A few glacial striae in the area indicate that the ice advance direction was at about 170° (Baker *et al.* 1982).

A recent airborne geophysical survey over Tannahill Township failed to identify significant bedrock electromagnetic conductors on the property (OGS 1984d). Total field magnetic data from the same survey indicate:

1) the presence of a prominent magnetic ridge trending 165°, parallel to and about 500 m west of the prominent, eastern cross fault. This ridge terminates in the northeastern part of the property, where its trend intersects the inferred location of the Kinojévis/Blake River Group contact.

2) The Kinojévis/Blake River Group contact has no visible magnetic signature on the property, probably due to low magnetic contrast between the magnesium-tholeiites of the Kinojévis Group and the calc-alkalic rocks of the Blake River Group.

Bedrock examined consists of two stripped exposures, both of which were partially blasted. Both stripped areas are within 10 m of the common post for claims 982942, 982943, 982945, and 982946, on a raised area on the eastern bank of the Magusi River. This location is indicated to be within the Blake River Group, approximately 200 m southeast of the contact with the Kinojévis Group (Jensen 1982).

The eastern stripped area (about 3 by 4 m) exposes light green/grey, carbonatized, amoeboid to rarely bun-shaped, south-facing, pillowed mafic or intermediate volcanic rocks. Most pillows are less than 1.5 m in maximum exposed dimension and are amygdaloidal. Amygdules at the darker green/grey pillow margins are concentrically distributed and 1 mm in size. Amygdules grade inward to the pillow centres, where they are randomly distributed and 3 mm in size. The amygdules consist of chlorite and calcite, quartz, quartz rimmed by calcite, pyrite rimmed by calcite, pyrite and (rarely) chalcopyrite. The interpillow matrix is generally dark green, chloritic, carbonatized, very fine grained and locally hyaloclastic. It contains 1 to (rarely and locally) 80 percent disseminated, fine-grained pyrite and wispy, fine-grained, disseminated chalcopyrite. Interpillow sulphide minerals tend to be coarser grained and more abundant where associated with calcite-quartz

masses and veinlets, which (rarely) cut individual pillows.

The western stripped area consists of a 0.5 to 3 m wide by 9 m long irregular face blasted into carbonatized, pillowed volcanic rocks identical to those in the eastern exposure described above. Blasted samples include interpillow pyrite and chalcopyrite with accessory bornite, malachite and azurite mineralization. Sulphide content of the interpillow matrix ranges from 1 to 90 percent, with essentially massive sulphide specimens rarely larger than a moderate-sized hand sample. One grab sample of interpillow quartz-calcite-pyrite-chalcopyrite contains very fine-grained, acicular, green tourmaline, and green, coarse-grained amphibole (actinolite?).

Economic deposits of base metal sulphide and precious metal mineralization are hosted by the Blake River Group in the Noranda area in Québec. Subeconomic base metal sulphide and precious metal deposits are known to occur in the Blake River Group in Ben Nevis Township, about 10 km south of the prospect area. Most of this mineralization has been interpreted to be of volcanogenic exhalative or related type (Grunsky 1982).

Many volcanogenic exhalative and related base metal sulphide deposits are associated with domains of altered rocks that typically are much larger than the economic mineralization. In Ben Nevis Township, sub-economic, Cu-Zn-Pb-Ag-Au vein and stockwork sulphide mineralization is associated with extensive sericite, chlorite, talc, carbonate and disseminated sulphide alteration (Wolfe 1977). On the Canagau Mines Limited property in Ben Nevis Township, pervasive carbonatization is associated with quartz-carbonate stockwork mineralization. Here, pervasive carbonatization has altered the volcanic rocks proximal to stockwork mineralization, while distal to the centre of carbonatization, carbonate alteration tends to be non-pervasive, and controlled by porosity (Grunsky 1980). Occurrence of tourmaline has also been described within a silicified zone in the area (Grunsky 1982).

On the Gagné/St. Amant Prospect, minimal overburden stripping has exposed base metal sulphide (up to 8.7 percent copper and 0.13 percent zinc in selected grab samples) and precious metal (up to 37 ppm silver and 580 ppb gold) mineralization hosted by pervasively carbonatized volcanic rocks of the Blake River Group. The type and style of this mineralization are identical to that known to be associated with stockwork-type base metal/precious metal mineralization in Ben Nevis Township, about 10 km to the south. Although no quartz-carbonate stockworks were observed in the outcrop, the occurrence of tourmaline in an interpillow quartz-carbonate mass hosted by pervasively carbonatized pillowed lavas may indicate proximity to such a paleo-hydrothermal system.

Further prospecting and exploration work on the property, and in the area, must proceed with the knowledge that potential exists for exhalative volcanogenic and related (e.g. stringer-type) mineralization. Work in the immediate vicinity of the showing should attempt to quantify the size, shape and polarity of the carbonatized zone, and to establish whether an associated zone of stringer-type mineralization exists. Farther along strike from the showing, both to the northwest and southeast, and up-section, to the southwest, the potential for exhalative massive sulphide deposits may exist. It should be noted that in Ben Nevis Township, a recent airborne electromagnetic and magnetic survey did not indicate the presence of significant electromagnetic bedrock conductors associated with known sulphide mineralization (Grunsky 1982). The lack of such conductors on the property is not, therefore, sufficient evidence to conclude that base metal sulphide mineralization is not present.

The 165°-trending cross faults and the 165°-trending magnetic ridge should be thoroughly prospected. Finally, because base metal sulphide deposits hosted by the Blake River Group may be stacked, the volcanic section stratigraphically underlying the showing to the northeast must also be considered to have the potential to host base metal and precious metal mineralization.

ACKNOWLEDGMENTS

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029. Metallogenic Studies in the Temagami Greenstone Belt, District of Nipissing

J.A. Fyon, and L. O'Donnell

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

This is the first year of a two-year metallogenic study in the Temagami greenstone belt, located approximately 100 km north of North Bay (Location Map). Mapping was carried out in the northeastern part of the belt, in Strathy Township (Figure 029.1), to a) integrate with areas mapped previously by the senior author in 1983 and 1984 (Crocket *et al.* 1984; Fyon and Crocket, 1986); b) investigate the numerous gold occurrences located in Strathy Township (Bennett 1978); c) investigate an apparent Mo-Cu-Au metal zoning, which is developed with respect to a belt-bounding intrusive complex (Chambers-Strathy Batholith), along a zone of deformation; and d) assess the potential for precious metal (Au, platinum group metals (PGM)) and volcanic-associated, base-metal, massive-sulphide mineralization. The study of PGM mineralization is being addressed by D.J. Good (Geologist, Precambrian Section, Ontario Geological Survey, *see* article 042, this volume).

METHODOLOGY

The northern half of Strathy Township was mapped at a scale of 1:7920. Only the Archean lithologies were examined in detail. The inter-relationships between lithological, stratigraphic, structural, and alteration characteristics of the belt were addressed. Parts of three properties (Net Lake layered intrusion (INCO Limited's claims), INCO Limited's Cooke Lake claims, and Manridge Explorations Limited's MacVeigh option) were mapped at a more detailed scale (1:1200).

The cooperative PGM research has focused on two tholeiitic, layered intrusions (the former Kanichee Mine (Ni-Cu-Pt) and the Net Lake layered intrusion) and a regionally extensive, conformable unit of ultramafic, fragmental rock, which has some komatiitic characteristics. This collaborative research is reported in more detail elsewhere (*see* D.J. Good, articles 042 and 043, this volume).

GENERAL GEOLOGY

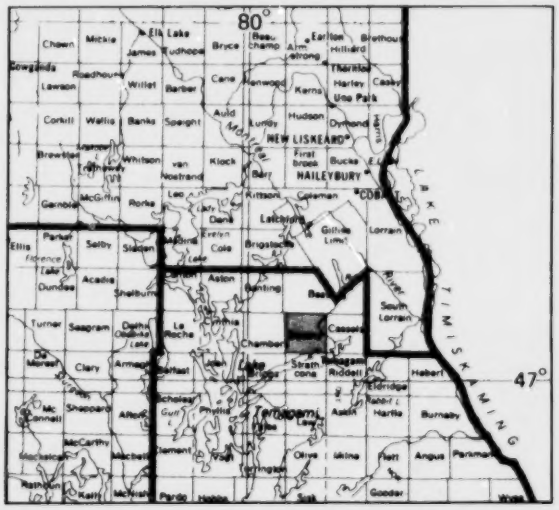
PROTEROZOIC LITHOLOGIES

The Proterozoic lithologies consist of Huronian metasediments, diabase intrusions, and Sudbury-type diabase dikes. These lithologies were not the focus of investigation this summer and are described in detail by Bennett (1978).

ARCHEAN LITHOLOGIES

Volcano-sedimentary Rocks

Tentatively, three volcanic groups and two sedimentary sequences are recognized. This subdivision is presented cautiously until a broader geological perspective is acquired and the structural relationships between the groups is better understood. Therefore, this is a geometrical, but not necessarily a chronological, subdivision.



LOCATION MAP

Scale : 1:1 584 000 or
1 inch to 25 miles

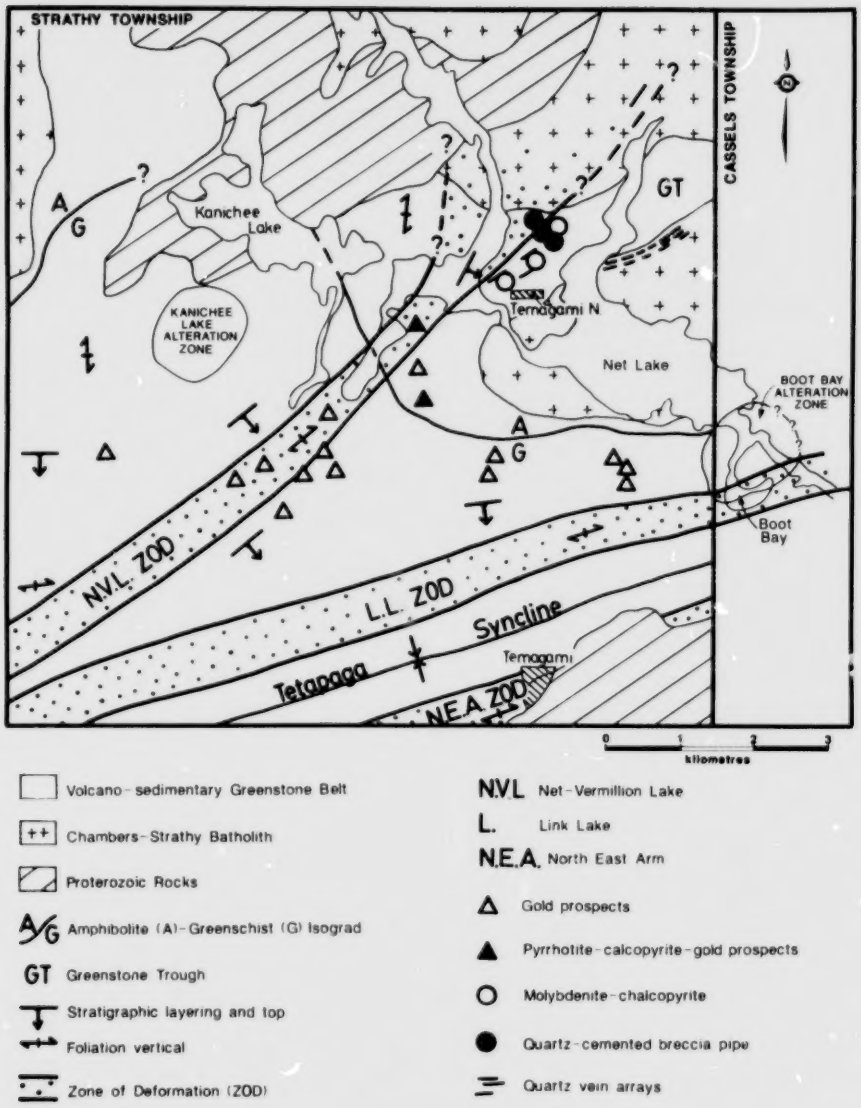


Figure 029.1. *Simplified geology of Strathy and part of Cassels Townships, District of Nipissing, illustrating the location of major zones of deformation, selected mineral occurrences, the greenschist-amphibolite grade metamorphic isograd, and two distinctive alteration zones (see text for discussion).*

Lower and Middle Volcanic Groups

The Lower and Middle Volcanic Groups each consist of a couplet having a tholeiitic base and a calc-alkalic top. Within the basal tholeiitic units, the more distinctive effusive flows are either variolitic or feldspar megaphyric. The calc-alkalic sequences are characterized by the presence of both effusive and pyroclastic flows. The mafic calc-alkalic flows are feldspar-hornblende(?)-phyric, the dacite flows are feldspar-hornblende(?)-quartz-phyric, and the rhyolite flows are feldspar-quartz-phyric.

Upper Volcanic Group

The Upper Volcanic Group consists only of tholeiitic basalt flows. Flows at the lower part of this group are interlayered with stratigraphically lower, epiclastic and chemical sediments. The Upper Sedimentary Sequence is described below.

Metasedimentary Sequences

Lower Metasedimentary Sequence

The Lower Metasedimentary Sequence, consisting of epiclastic and chemical (sulphide and oxide facies iron formation) deposits, separates the Lower and Middle Volcanic Groups. This poorly exposed clastic

unit consists of heterolithic, volcaniclastic sediments, some of which contain chert and magnetite-chert clasts.

An ultramafic, fragmental unit occurs within the Lower Metasedimentary Sequence. Preliminary descriptions of this rock are given by Bennett (1978) and Fyon and Crocket (1986). It consists of centimetre- to millimetre-size, rounded to angular, serpentine-rich fragments, set within a talc-rich matrix. In some areas the fragments are angular in shape, closely resembling a hyaloclastitic texture. Locally, distinct layering is developed, but this is not a ubiquitous characteristic. Where layered, a size grading and apparent bulk-chemical change, based on mineralogical changes, is apparent. The ultramafic fragmental rock is in contact with, but stratigraphically above, a regionally extensive unit of chert-magnetite-ferruginous silicate iron formation (West and North Pit iron deposits, Sherman Mine). Several, thin (5 m?) layers of similar ultramafic rock are exposed discontinuously for approximately 10 km along strike, in this stratigraphic setting, closely associated spatially with oxide-facies iron formation. However, it is not certain if the multiple layers of fragmental ultramafic rock represent separate units or a structural repetition of a single unit. A cursory chemical characterization of this lithology, carried out following the 1984 field work (Fyon and Crocket 1986), revealed that some chemical characteristics of the ultramafic rock are consistent with it having a komatiitic affinity; however, some peculiar chemical anomalies exist which warrant clarification before the chemical affinity of this lithology can be assigned with certainty.

Upper Metasedimentary Sequence

The Upper Metasedimentary Sequence lies at the top of the Middle Volcanic Group, along the transitional interface between the Middle and Upper Volcanic Groups. It consists of oxide-facies iron formation (South and East Pit iron deposits, Sherman Mine) and epiclastic, turbiditic metasedimentary deposits (Bennett 1978; Fyon and Crocket 1986). No ultramafic unit has been recognized within the Upper Metasedimentary Sequence.

Intrusive Rocks

Early Felsic Intrusions

Quartz-, feldspar-, quartz-feldspar-phyric, and pyroxenitic and gabbroic dikes are common within the volcanic stratigraphy, particularly north and northeast of the Kanichee Mine along the south shore of Kanichee Lake. It is possible that these dikes represent subvolcanic equivalents of the extrusive mafic and felsic Archean volcanic lithologies, although it is extremely difficult to distinguish the dikes from the mesoscopically similar, younger, postgranitoid varieties.

Dioritic and Quartz Dioritic Intrusions

The more conspicuous of these intrusions are the Link Lake Intrusion, which crops out along the Milne-Sherman road, west of Highway 11, and the COMINCO Intrusion, which crops out between Kanichee Lake and Net Lake. This latter intrusion is cut by auriferous, sulphide-mineral-bearing quartz veins. The relative age of these intrusions with respect to the belt-bounding granitoid intrusions is uncertain, although the dioritic intrusions lie within and are deformed by major zones of deformation.

Mineralogically, these intrusions consist of feldspar, hornblende(?), and lesser amounts of quartz. This resembles the phenocryst mineralogy of the calc-alkalic andesite and dacite flows, to which the intrusions may be genetically related.

Layered, Tholeiitic Intrusions

Two intrusions of this type were examined: the Kanichee (Ajax) and the Net Lake layered complexes. The Kanichee Intrusion, site of the Kanichee Mine (a past producer of Cu, Ni, and PGM), has been described most recently by James and Hawke (1984). The mineralogy of the ore has been described by Cabri and Laflamme (1974). Results of this summer's investigation of this intrusion are reported by D.J. Good (*see* this volume).

The Net Lake layered complex intrudes into the lower part of the Middle Volcanic Group and crops out approximately 1 km to the east of the Kanichee Intrusion in northwestern Strathy Township. It has a strike length of approximately 4 km, considerably longer than illustrated on Colour Map 2323 (Bennett 1978). Field work in 1987 traced this intrusion for approximately 2 km northeast of Highway 11, almost to the Strathy-Cassels Township boundary, consistent with the observations of Knight (1920). In this area, the tholeiitic intrusion is engulfed by a granitoid intrusion (Strathy-Chambers Batholith).

Southwest of Net Lake, the mafic intrusion consists of a lower pyroxenite phase which is overlain by a heterogeneous, gabbro-anorthositic gabbro phase. The uppermost part of the intrusion appears to consist of a quartz-rich (>40%), feldspathic unit which may represent a recrystallized granophyre. Northeast of the Town of Temagami North along the northeast shore of Net Lake, the pyroxenite phase of the intrusion is lacking, and coarse-grained (>1 cm) gabbro and anorthositic gabbro predominate. Compositional layering throughout the complex is developed on a large scale (tens of metres), and is grossly conformable with the stratigraphic attitudes of the volcano-sedimentary lithologies.

Strathy-Chambers Batholith

This quartz monzonite intrusion occupies most of the northeastern and extreme northwestern corners of Strathy Township (Figure 029.1). It intrudes the Archean volcano-sedimentary belt, including the layered, tholeiitic intrusions. A marked reddening of the feldspars is a common, but not a ubiquitous, feature near the outer margin of the intrusion. On the basis of the colouration habit, the reddening is tentatively attributed to hematite staining of the plagioclase feldspar.

Northeast from the Town of Temagami North, a tongue of volcanic rock (Middle Volcanic Group) extends into the batholith, nearly to the Cassels Township boundary. These rocks, referred to as the

"Greenstone Trough" (Figure 029.1), have been extensively intruded by the Strathy-Chambers Batholith, producing a zone of intrusion breccia which extends nearly to the Cassels Township boundary.

Postgranite Intrusions

Quartz-, feldspar-, and quartz-feldspar-phyric felsic dikes and pyroxenite, biotite-rich lamprophyre and very fine grained (gabbroic?) mafic dikes cut both the volcano-sedimentary rocks and the Strathy-Chambers Batholith. Only where they cut the granitoid rocks can an unequivocal distinction be made between these dikes and mesoscopically similar varieties which predate the intrusion of the Strathy-Chambers Batholith.

LARGE–SCALE STRUCTURAL FEATURES

FOLDS

The largest recognizable fold structure in Strathy Township is the Tetapaga Syncline (Bennett 1978). Its axial plane follows an easterly trend across the southern part of the township, parallel to the stratigraphic attitudes of the volcanic and metasedimentary units (Figure 029.1). Limited data indicate that this fold has a shallow easterly plunge. Rocks of the Middle Volcanic Group and the Upper Metasedimentary Sequence are repeated on either side of the synclinal axis. The tholeiitic basalts of the Upper Volcanic Group occupy the core of the syncline.

ZONES OF DEFORMATION

Three major zones of deformation are defined on the basis of localized and intense fabric development: the Link Lake, the Northeast Arm, and the Net Lake-Vermilion Lake Zones of Deformation (Figure 029.1; Bennett 1978: Fyon and Crocket 1986). In addition, several narrower zones of deformation, including the Big Dan, Arsenic Lake, and MacVeigh (Manridge Explorations Limited's option) structures, occur outside of the major zones of deformation.

Link Lake and Northeast Arm Zones of Deformation

The Link Lake and Northeast Arm Zones of Deformation represent paired zones which are developed on either side of the Tetapaga Syncline. These zones of high strain are characterized by very strongly developed flattening and a strong vertical extension lineation. Foliation has an easterly trend with a vertical to subvertical dip, approximately parallel to bedding attitudes. Within the zones of deformation, subhorizontal, fibrous, calcite-filled extension fractures are preferentially localized in deformed mafic, calc-alkalic rocks. The orientation of fiber growth reflects the strong vertical extension which characterizes these deformation domains. Pre- and syndeformational quartz and ferroan-carbonate veins, also present within the zones of high strain, are symmetrically folded about foliation-parallel, fold axial surfaces.

Generally the highest strain is developed within calc-alkalic, felsic, pyroclastic flow units and the spatially associated, metasedimentary rocks, which are exposed closest to the synclinal axis of the Tetapaga Syncline. Concentration of strain in these units may reflect their behaviour as inherently incompetent domains, interlayered between two blocks (domains) of more competent mafic volcanic flows. The greatest accumulation of these competent, mafic rocks occurs in the core (Upper Volcanic Group) and outer limbs (Middle Volcanic Group) of the Tetapaga Syncline.

The deformation fabrics are symmetrical, reflecting overall coaxial (irrotational) strain (pure shear). An east-trending foliation is also developed in other units outside the zones of deformation, although it is not as strong as in the felsic rocks within the zones of deformation. The development of these two zones of deformation may be the result of continued diapirism and associated north-south compression, which was originally responsible for the formation of the Tetapaga Syncline.

Net Lake-Vermilion Lake Zone of Deformation

The trend of this zone is northeasterly, oblique to regional east-trending bedding orientations, coincident with a line passing through Vermilion Lake and extending into the western part of Net Lake. The zone of intense fabric development is approximately 1 km in width, and coincides with the transitional contact zone between the Lower and Middle Volcanic Groups. The lack of mesoscopic, asymmetric kinematic indicators is consistent with the zone's development in response to a dominant component of pure shear, although a component of simple shear does exist. Major support for the simple shear component comes from the transposition of volcanic and sedimentary lithologies into parallelism within the zone, which defines a sinistral horizontal component, and the presence of two shear zones, exposed along Highway 11 north of the Town of Temagami North. These two shear zones, the larger of which is about 3 m in width, show well developed kinematic asymmetry, indicating a sinistral horizontal component of shear with a west-side-up, vertical component. The larger of these two shear zones cuts the outer margin of the Strathy-Chambers Batholith, while the second, narrower shear zone is developed in amphibolitized, tholeiitic basalt flows. Kinematic asymmetry is observed within the main zone of deformation, but it is not well developed and is often too subtle to detect mesoscopically. Where a sense of shear can be determined, a west-side-up, vertical component is more commonly, but not uniquely, indicated.

Other Structures

The MacVeigh structure, currently being explored by Manridge Explorations Limited for gold, is located immediately west of the Net Lake layered intrusion and east of the south bay of Net Lake. The foliation in the main shear zone has a northerly to northwesterly trend and a steep westerly dip. Kinematic asymmetry indicates a dextral horizontal component with a west-side-up, vertical component.

The Arsenic Lake and Big Dan structures are both characterized by north-trending foliation, having a subvertical to steep, westerly dip. No consistent, mesoscopic asymmetry was observed; however, both stuctures' extension lineations plunge steeply south.

Regional Foliation

The orientation of foliations developed throughout Strathy Township is variable. Southeast and southwest of the Net Lake-Vermilion Lake Zone of Deformation, the foliations are east-trending and reflect the orientation of the Link Lake Zone of Deformation. In central Strathy Township, foliation orientations have a northeastern trend and reflect the trend of the Net Lake-Vermilion Lake Zone of Deformation. In northern and northwestern Strathy Township, a moderate to very strong, north-trending foliation is developed. The origin of this north-trending foliation is as yet unknown, but it is also developed within the outer margin of the Strathy-Chambers Batholith; hence, the foliation must have developed synchronously with, or after, batholith intrusion.

Temporal Relationships

In the southwestern corner of Strathy Township, foliations related to both the Link Lake and Net Lake-Vermilion Lake Zones of Deformation are observed to crosscut one another. The east-trending foliation of the Link Lake Zone is overprinted by, and therefore predates, the northeast-trending foliation of the Net Lake-Vermilion Lake Zone of Deformation. This, in turn, indicates that the development of the Net Lake-Vermilion Lake Zone of Deformation postdated that of the Tetapaga Syncline. The Net Lake-Vermilion Lake Zone of Deformation cuts and therefore postdates the intrusion of the outer margin of the Strathy-Chambers Batholith. The relative age of the minor structures is less well constrained, although the the Big Dan shear zone affects a feldspar-phyric dike which cuts the outer margin of the Strathy-Chambers Batholith.

ALTERATION

REGIONAL METAMORPHIC GRADE

Archean volcano-sedimentary lithologies have attained greenschist or lower metamorphic grades, except for an amphibolite-grade contact-metamorphic aureole which is developed about the Strathy-Chambers Batholith (Figure 029.1). The restriction of the amphibolite-grade rock to the "Greenstone Trough", and immediately adjacent to the margin of the Strathy-Chambers Batholith, indicates that peak amphibolite-grade metamorphism was attained during the intrusion of the Strathy-Chambers Batholith. The width of the amphibolite-grade contact aureole, adjacent to the Chambers-Strathy Batholith, is generally less than 100 m. However, in northeastern Strathy Township, southwest of Net Lake, the surface trace of the amphibolite/greenschist isograd departs from the exposed margin of the Strathy-Chambers Batholith, and extends up to 1 km away (Figure 029.1).

EARLY ALTERATION

These alteration assemblages are contact metamorphosed by the intrusion of the Strathy-Chambers Batholith, and may have developed in response to hydrothermal activity early in the diagenetic history of the Archean volcano-sedimentary succession.

Boot Bay Alteration Pipe

A large area of silicified, tholeiitic and calc-alkalic rock of the Middle Volcanic Group, in which localized areas of chloritization and sericitization occur (Figure 029.1), is exposed along southeastern Net Lake in the Boot Bay area, on the Strathy-Cassels Township boundary (Fyon and Crocket 1986). Isolated patches of silicified rock also occur to the west, in Strathy Township, up to the north-trending segment of Ontario Northland's railroad track. The chloritization is manifest in the silicified rock as veinlets and centimetre-sized ovoids. Close to the Strathy-Chambers Batholith, this alteration is expressed by a dark green, fibrous amphibole(?) mineral, although the same textural habit is preserved.

Exposed on one island and on the northeastern tip of a peninsula in the centre of the silica alteration zone (in the Boot Bay area) is a zone of sericitization. This zone appears to be enveloped by the patchy and veinlet-style chlorite alteration, although the extent of these alteration assemblages has not been traced to the east of Net Lake. Similar zones of chloritization and sericitization are exposed immediately to the west of the Strathy Township boundary, and are always developed in close proximity to silicified rock. However, because of very poor exposure, the extent to which these alteration assemblages are developed to the west of the Strathy-Cassels Township boundary is not well constrained. While no cordierite was found in the amphibolite-grade basaltic flows adjacent to the Strathy-Chambers Batholith, one exposure of potassium feldspar bearing basalt was observed, possibly representing the prograde manifestation of the sericitic, potassic alteration.

The similarity between these alteration assemblages and those frequently observed in proximity to volcanic-associated, base-metal massive-sulphide mineralization, and the presence of approximately two dozen pyrrhotite-pyrite-chalcopyrite occurrences in the Boot Bay area, highlight the metallogenic potential of this large area of alteration.

Kanichee Lake Alteration Zone

A broad zone of alteration, approximately 0.5 km in diameter, is located northwest of the Kanichee Mine (Figure 029.1). Within this zone, intermediate, calc-alkalic flows of the Lower Volcanic Group are bleached and cut by veinlets and ovoids of a green, fibrous amphibole(?). This green amphibole resembles the green amphibole which occurs in the Boot Bay alteration zone, close to the margin of the Strathy-Chambers Batholith. The bleaching is attributed in part to silicification, but replacement of the flows by white feldspar (albitization?) is also evident. No sulphide-mineral occurrences were found associated with this zone of alteration.

ALTERATION WITHIN ZONES OF DEFORMATION

Within those segments of the Link Lake, Northeast Arm, and Net Lake-Vermilion Lake Zones of Deformation which transect domains of subamphibolite metamorphic grade, mafic and intermediate lithologies have been variably replaced by ferroan carbonate.

Frequently, calcite and chlorite-rich assemblages form alteration envelopes about the ferroan-carbonate-rich assemblages. Hydrothermal carbonate in carbonatized rhyolitic rock exists as veins and disseminated grains, rather than as a matrix replacement. More typically, rhyolitic rock within these zones of deformation contains abundant white mica (sericite ?). Alteration of volcanic lithologies along that segment of the Net Lake-Vermilion Lake Zone of Deformation which cuts lithologies of amphibolite metamorphic grade, is not characterized by the presence of hydrothermal carbonate in mafic lithologies and white mica in felsic rock is rare.

Locally, within the the Net Lake-Vermilion Lake Zone of Deformation, oxide-facies iron formation has been sulphidized. In general, pyrrhotite occurs as the predominant sulphide mineral where the replacement occurred closer to the Strathy-Chambers Batholith, within the amphibolite-grade contact metamorphic aureole (e.g. INCO Limited's Net Lake iron formation Property). Pyrite, chalcopyrite, sphalerite, arsenopyrite, stibnite?, and minor pyrrhotite are the characteristic sulphide minerals within sulphidized segments of iron formation which occur within the subamphibolite metamorphic grade terrains (e.g. Mayfair Property).

Basaltic rock within the Arsenic Lake and Big Dan shear zones has been altered to chlorite. Virtually no hydrothermal carbonate occurs in either of these two zones. Silicification, manifest by pervasive replacement by silica, is observed adjacent to the Arsenic Lake shear, but its distribution is limited.

Thus, the rock alteration assemblages within those segments of the Link Lake, Northeast Arm, and Net Lake-Vermilion Lake Zones of Deformation, which cut lithologies of subamphibolite metamorphic grade, are grossly similar. They are dominated by carbonate-rich assemblages, despite their differences in deformation style and chronology. This contrasts with altered lithologies which occur within the Big Dan and Arsenic Lake shear zones, where ferroan carbonate is virtually absent, regardless of proximity to the margin of the Strathy-Chambers Batholith.

METALLOGENY

BASE-METAL MASSIVE-SULPHIDE MINERALIZATION

The felsic volcanic rocks, which constitute the top of the Middle Volcanic Group, appear to have potential to host volcanic-associated, base-metal, massive-sulphide mineralization (Fyon and Crocket 1986). The silica- and chlorite-rich alteration zones exposed in eastern Strathy and western Cassels Townships (Figure 029.1) represent the most favourable exploration targets observed during this study.

SULPHIDE MINERALIZATION WITHIN LAYERED INTRUSIONS

Sulphide-mineral concentrations, having several temporal, mineralogical, and textural characteristics, are common throughout the layered, tholeiitic intrusions. These are described by D.J. Good (this volume).

GOLD OCCURRENCES

More comprehensive descriptions of gold properties are given by Savage (1935), Moorhouse (1942), and Fyon and Crocket (1986), and only some general characteristics are discussed here. Most of the gold showings occur within the Net Lake-Vermilion Lake Zone of Deformation (*see* chart in Bennett 1978). Many of these showings represent restricted pyrite concentrations within the sheared lithologies at the top and base of the Lower and Middle Volcanic Groups respectively. Quartz veins, containing gold and base-metal sulphide minerals (chalcopyrite, sphalerite, galena), arsenopyrite, pyrite, and minor pyrrhotite, are typical of those properties which have undergone extensive development or exploration. The quartz veins can be localized within discrete shear zones in quartz diorite (e.g. COMINCO Limited's Property), within sulphide-facies (e.g. INCO Limited's Cooke Lake claim group) or oxide-facies (e.g. Mayfair Property) iron formation, and within mafic volcanic rock that has been replaced by ferroan carbonate (e.g. Beanland Property).

Those gold showings which lie outside the Net Lake-Vermilion Lake Zone of Deformation are localized in north-trending (±30°), chloritized shear zones, where hydrothermal ferroan carbonate is generally absent. Of these, the Big Dan (United Reef Petroleums Limited), the Penrose or Arsenic Lake (Stroud Resources Limited-Lacana Mining Corporation joint venture) and the Manridge Explorations Limited MacVeigh option are typical. The dominant habit of mineralization on the former two properties consists of impregnated pyrrhotite, pyrite, chalcopyrite, and arsenopyrite. Quartz veins are present, but do not constitute a dominant habit. On the Manridge option, pyrrhotite, pyrite, and chalcopyrite occur in zones of impregnation and less commonly in quartz veins within the main shear. These three prospects are located close to, if not on, the surface trace of the greenschist-amphibolite contact-metamorphic isograd.

Alteration Associated With Auriferous Systems

Of the auriferous systems examined, basaltic host rock has been altered to ferroan-carbonate- (e.g. Perron or Beanland), chlorite (e.g. Big Dan), and/or silica-rich (e.g. Arsenic Lake or Penrose) assemblages, whereas felsic rocks have been either sericitized or impregnated with ferroan carbonate. These alteration assemblages, spatially related to zones of anomalous gold concentration, are not different from those alteration assemblages which characterize the major zones of deformation or those alteration zones developed outside the zones of deformation (e.g. Boot Bay). Thus, within a major zone of deformation, no particular alteration assemblage is uniquely specific to the gold mineralization.

Metal Concentration Along Zones of Deformation

As noted by Bennett (1978), the Net Lake-Vermilion Lake Zone of Deformation is the preferred locus of gold concentration in the Temagami greenstone belt. The localization of gold along this zone of deformation, and the virtual absence of gold showings along either the Link Lake or Northeast Arm Zones of De-

formation, may be related to several factors. The Net Lake-Vermilion Lake Zone of Deformation developed later in the history of the greenstone belt. Conversely, the other two major zones of deformation developed earlier, perhaps synchronously, with diapirism. This is a common observation, typical of most of the gold-associated zones of deformation in the Superior Province (cf. Andrews *et al.* 1986). The Link Lake and Northeast Arm Zones of Deformation appear to have developed largely under irrotational, deformational regimes; conversely, the Net Lake-Vermilion Lake Zone of Deformation developed in response to a greater simple shear (rotational) component. This preferred localization of gold within zones of deformation, which developed in response to a greater component of simple shear, was also observed in the Confederation Lake area of the Uchi Belt (Fyon and O'Donnell 1986) and this relationship may be of fundamental importance.

The following evidence indicates that the concentration of the gold occurrences along the Net Lake-Vermilion Lake Zone of Deformation may also be related to the passage of anomalous volumes of fluid along this structural zone. The greenschist-amphibolite contact-metamorphic isograd generally follows closely along the margin of the Strathy-Chambers Batholith; however, in one area it departs markedly from the margin of the batholith. This area's trend of maximum departure approximately corresponds to the southwest projection of the "Greenstone Trough" and the Net Lake-Vermilion Lake Zone of Deformation. The orientation of this isograd may reflect the southwest, shallow dip of the Strathy-Chambers Batholith beneath the "Greenstone Trough" and/or the passage of anomalous volumes of fluid through the "Greenstone Trough", in part localized by the Net Lake-Vermilion Lake Zone of Deformation. Additional evidence that anomalous volumes of fluid did access the "Greenstone Trough" is provided by a) the development of an extensive zone of quartz veining, apparently not associated with base- or precious-metal mineralization, in the Strathy-Chambers Batholith on the southeast margin of the "Greenstone Trough" (Figure 029.1); b) the existence of an extensive zone of hydraulically fractured, amphibolitized, basaltic rock, manifest as a quartz- and quartz-feldspar-cemented, chalcopyrite-molybdenite-bearing, breccia pipe (in the "Greenstone Trough") adjacent to the contact with the Strathy-Chambers Batholith (Figure 029.1); and c) the occurrence of a chalcopyrite-molybdenite-bearing quartz vein array within the "Greenstone Trough", to the southwest of the breccia pipe.

Evidence that the fluid passage through the "Greenstone Trough" was synchronous with or postdated both peak metamorphism and the intrusion of the outer margin of the Strathy-Chambers Batholith is provided by the presence of a quartz-cemented breccia pipe and a cogenetic quartz vein array which cut amphibolitized basalt and the outer margin of the Strathy-Chambers Batholith. The amphibolitized basalt fragments within the breccia pipe and basalt adjacent to the quartz veins do not appear to have been altered by the hydrothermal fluids; that is, the amphibolitized basalt appears to have existed in equilibrium with the hydrothermal fluids.

Thus, anomalous volumes of hydrothermal fluid appear to have passed through the "Greenstone Trough" synchronously with or slightly postdating the intrusion and consolidation of the outer margin of the Strathy-Chambers Batholith. During the influx of this hydrothermal fluid, quartz and quartz-, feldspar-, chalcopyrite-, and molybdenite-bearing vein systems were precipitated. The excursion of the amphibolite-greenschist metamorphic isograd away from the immediate margin of the Strathy-Chambers Batholith is a possible consequence of this hydrological event. Similarly, the high frequency of gold occurrences, localized along the Net Lake-Vermilion Lake Zone of Deformation, and the fewer number of gold occurrences which are localized in shear zones oriented radially to the amphibolite-greenschist metamorphic isograd, are also possible expressions of a major fluid-influx event through the "Greenstone Trough" late in the diapiric history of the Strathy-Chambers Batholith.

The Net Lake-Vermilion Lake Zone of Deformation appears to have served as a conduit along which metalliferous fluids passed. It defines an important target for gold exploration.

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030. Geology of Brigstocke and Kittson Townships, District of Timiskaming

Peter Born[1] and G.H. Burbidge[2]

[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Graduate Student, University of Ottawa, Ottawa, Ontario.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

The map area (200 km^2) consists of Brigstocke Township and the southern two-thirds of Kittson Township. It is located in the District of Timiskaming some 5 km southwest of Latchford, 15 km southwest of Cobalt, and 20 km north of Temagami. The area is bounded by Latitudes 47°13′49″N and 47°22′30″N, and Longitudes 79°47′00″W and 81°01′00″W.

Road access to the area is limited to a gravel road from Highway 11 to Anima Nipissing Lake which provides water access to much of Brigstocke Township. Kittson Township is accessible via the Montreal River from Portage Bay. Entry by float-plane into Gullrock, Kittson, Kitt, High Falls, Best, and Mountain Lakes provides water access to the remainder of the area.

MINERAL EXPLORATION

The information reported here, if not stated otherwise, is taken from the assessment files, Resident Geologist Office, Ontario Ministry of Northern Development and Mines, Cobalt.

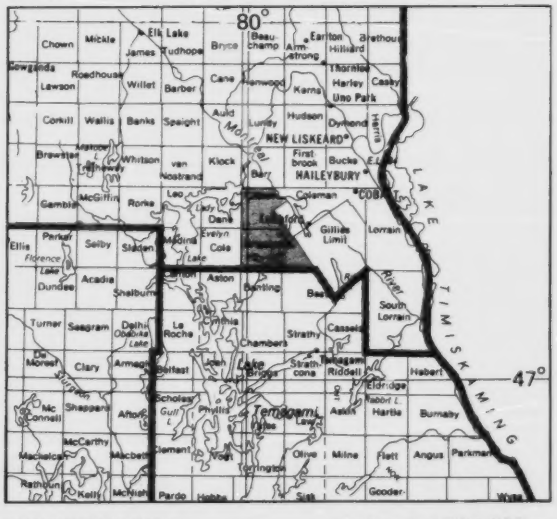
Mineral exploration for silver and cobalt within the map area dates from 1910 with prospecting, trenching, shaft-sinking, and tunneling at the Canadian Prospect (Cobalt-Kittson Mine) located on the Montreal River (Kittson Township) and at the Shakt-Davis Mines on the northeastern shore of Kitt Lake near the Kittson-Coleman township boundary.

Similar prospecting occurred around Anima Nipissing Lake at Sugarloaf Island, and Crowrock Bay and to the north of Brigstocke Lake (Brigstocke Township).

Between 1924 and 1926, an adit and extensive lateral underground drifting were completed at the Shakt-Davis Mine by Cresent Silver Cobalt Mining Company Limited. Later underground development by H. Davis, from 1938 to 1940, resulted in the completion of two underground levels with 442 m of lateral drifts and crosscuts and a 76 m winze. There are, however, no production records and mining development ceased in 1940. Limited diamond drilling of an unknown amount was carried out in 1951 and was followed by minor underground development in 1953 and 1964 by Aconic Mining Corporation.

Mine development at the Canadian Prospect was carried out from 1927 to 1930 by The Cobalt-Kittson Mines Limited. It resulted in a 191 m deep shaft and 450 m of lateral drifting on three underground levels. The total production of the mine was 600 pounds of smaltite; operations ceased in 1930. An unknown amount of diamond drilling followed the temporary dewatering of the mine in 1949 (Johns 1985).

Subsequent exploration for silver and cobalt in Brigstocke Township by C. Cameron in 1956 resulted in a diamond-drill program consisting of three holes



LOCATION MAP

Scale : 1:1 584 000 or
1 inch to 25 miles

for a total of 223 m. The work was carried out in an area of previous trenching and shaft-sinking (1913) adjacent to the northern end of Brigstocke Lake.

A ground resistivity survey was carried out by Temagami Mining Company Limited in the vicinity of a magnetite showing on Mountain Lake in southeastern Brigstocke Township.

During 1970, Tashota-Nipigon Mines Limited carried out an extensive exploration program in the Crowrock Bay area of Anima Nipissing Lake in northeastern Brigstocke Township. It consisted of geological, geochemical, and ground electromagnetic and magnetic surveys, and trenching and stripping in an area which had been previously prospected in the early 1900s.

GENERAL GEOLOGY

The earliest geological mapping in the area was done on a reconnaissance scale by Barlow (1899), DeLury (1908), and Todd (1926). Subsequent and more detailed mapping to the west of the map area was carried out by Card *et al.* (1973) in the Maple Mountain area. This includes a narrow 1200 m strip inside the map area along the western margin of Brigstocke and Kittson Townships. Areas adjacent to the map's northern boundary were mapped by Johns (1985) and include the northern one-third of Kittson Township. Mapping in areas to the east and south was done by Thomson (1963) and Smyk and Oswiacki (1986) respectively.

Underlying the map area are Archean supracrustal and plutonic rocks, Early Proterozoic supracrustal and intrusive rocks, and Middle Proterozoic (Keweenawan) dike rocks, namely diabase and lamprophyre.

Archean rocks underlie the southern part of Brigstocke Township and consist mainly of felsic plutonic and migmatitic rocks with lesser mafic metavolcanics.

Mafic metavolcanics are characteristically fine- to medium-grained amphibolites which exhibit varying degrees of migmatization (Mehnert 1971). Similar rocks have been described in Banting and Best Townships to the south of Brigstocke Township by Smyk and Oswiacki (1986).

The felsic plutonic rocks consist of a heterogeneous assemblage of both biotite- and hornblende-bearing tonalite, trondhjemite, quartz diorite, mafic diorite, diorite, granite, and granodiorite. Crosscutting relationships indicate that granodiorite and granite are the younger rock types. Minor inclusions of metasediments and metavolcanics occur in places and may represent roof pendents as suggested by Smyk and Oswiacki (1986).

A subsequent second cycle of Archean igneous activity is minor and represented by several outcrops of ultramafic and komatiitic-basalt rock types in the Mountain Lake area. Crosscutting relationships, illustrated by an ultramafic feeder dike cutting Archean migmatites, indicate that the second igneous cycle postdates the main felsic plutonic migmatite event. Nearby, a probable extrusive equivalent occurs as an outcrop of an ultramafic flow/sill (1 m thick) overlain by a vesicular komatiitic basalt. These peridotitic, ultramafic rocks are typically magnetite-rich and exhibit light blue-grey fresh surfaces and chocolate brown weathered surfaces with deeply weathered carbonate rinds. Fine-scale, and criss-crossing cooling and/or jointing millimetre-sized textures occur at both the top of the ultramafic flows and at the margins of the ultramafic dike. A few other peridotite dikes or sills occur and are found north of nearby Best Lake.

Archean felsic plutonic rocks are also intruded by rare north- and northwest-trending, fine-grained, Archean diabase dikes which vary in width from 10 to 100 cm.

Early Proterozoic rocks of the Huronian Supergroup, namely the metasediments of the Gowganda and overlying Lorrain Formations, underlie large parts of the map area. The local, tectonically, undisturbed stratigraphic section, as shown in Figure 030.1, is about 2000 m thick and is exposed in an east-trending synclinorium which dips 12° to the north.

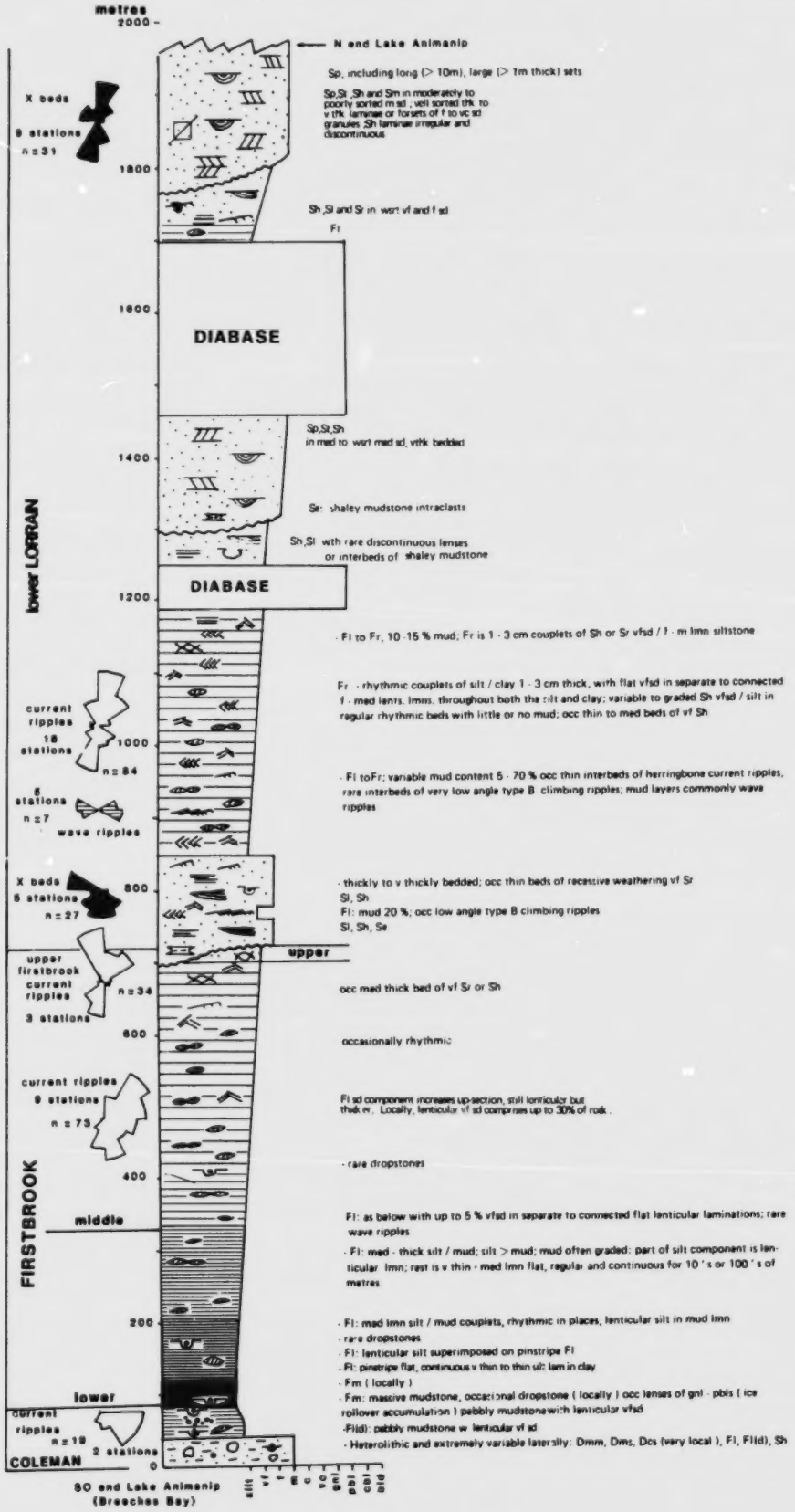
The Gowganda Formation consists of a lower unit, the Coleman Member, and an upper unit, the Firstbrook Member.

Rocks of the Coleman Member occur as a 100 m thick blanket (Figure 030.1) which is unconformably draped on Archean basement rocks in southern Brigstocke Township. These rocks include a local basal breccia (10 to 200 cm thick) overlain by poorly sorted diamictites containing mud-, sand-, and gravel-size constituents (Mustard 1985). Both massive and stratified matrix-supported diamictites occur and are believed to represent extensive debris flows. Clast-supported conglomerates and both pebbly and nonpebbly shaley mudstones with interlaminated siltstone and very fine sandstone are other common lithologies. The disappearance of the thin lenticular sandstone beds marks the upper limit of the Coleman Member. Metasediments of the Coleman Member are characterized by rapid lateral lithofacies changes and the presence of "dropstones", indicative of deposition in a glaciomarine environment at the edge of a continental ice shelf (Miall 1985).

The Firstbrook Member is approximately 600 m thick (Figure 030.1) and consists of a single, coarsening-upward sequence of fine-grained rocks (mud, silt, and minor very fine sand—Fl, Fm, and Fr lithofacies, Figure 030.1).

These metasediments overlie the Coleman Member and occur as an east-trending unit in the southern half of Brigstocke Township and throughout the central part of Kittson Township. The sequence is divisible into a lower, middle, and upper unit following the criteria of Rainbird (1985), although the uppermost unit is thin, poorly exposed, and absent in some parts of the map areas. Interlaminated shaley mudstone and siltstone occur in the lower unit with the proportion of silt <50% of the rock. In the middle unit, siltstone constitutes >50% of the rock, whereas the proportion of sandstone to siltstone plus shaley mudstone is >50% in the upper unit. Characteristic herringbone crosslaminations, which indicate a north-northeast-oriented bipolar paleocurrent distribution are common sedimentary structures of the Firstbrook Member.

COMPOSITE STRATIGRAPHIC SECTION, ANIMA NIPISSING LAKE



LEGEND

- current ripples (Sr)
- wave ripples
- herringbone X-laminations
- separate lenticular laminations (thick, flat)
- flaser bedding
- connected lenticular laminations
- wavy bedding
- type "B" climbing ripples
- muddy intraclasts (Se)
- flat lamination
- low angle trough scours (Sl)
- planar crossbeds (Sp)
- trough crossbeds (St)
- massive
- ball-and-pillow
- mudcracks
- erosional contact
- gradational or conformable contact

SUMMARY OF FACIES CODES

Sand:

- Se: erosional scours with lag of shaley mudstone intraclasts
- Sh: horizontal or subhorizontal stratification
- Sl: shallow trough scours with low angle crossbed infill
- Sm: massive sandstone

Fines:

- Fl: mudshale with minor sandstone
- Fm: mudstone
- Fr: rhythmically inter-laminated fines

Diamictite:

- Dmm: massive, matrix-supported
- Dms: stratified, matrix-supported
- Dcm: massive, clast-supported
- Dcs: stratified, clast-supported

ABBREVIATIONS

sd:	sand	f:	fine	wsrt:	well sorted
gnl:	granules	m:	medium	lents:	lenticular
pbls:	pebbles	vc:	very coarse	lmn:	laminations
vf:	very fine	vthk:	very thick	occ:	occasional

Figure 030.1. *Composite stratigraphic section, Anima Nipissing Lake.*

The base of the Lorrain Formation is placed, following the criteria of Johns (1985) and Rainbird (1985), at the base of the lowermost medium- or thickly-bedded arkose unit (Figure 030.1).

Rocks of the lower Lorrain Formation locally have a thickness of 1300 m and underlie most of the northern half of the map area. The lowermost unit consists of a well sorted, generally horizontally laminated, very fine and fine-grained, thickly-bedded arkose. Characteristic of this unit are shaley rip-up clasts, shallow-scours, and the presence of some 5 to 30 m wide shallow channels. Overlying this is a 350 m thick, coarsening-upward unit of laminated shaley mudstones, siltstones, and very fine grained sandstones (Fl and Fr lithofacies, Figure 030.1). It is similar in appearance to rocks of the upper and middle Firstbrook Member of the Gowganda Formation. This part of the section, however, is only present in the proximity of Anima Nipissing Lake and appears to pinch out further to the north. It also marks the base of the second of three coarsening-upward cycles. The uppermost exposed part of the third cycle consists of a moderate- to poorly-sorted, medium-grained arkosic sandstone with common planar and trough crossbeds.

Metasediments of the Firstbrook Member (Gowganda Formation) and the Lorrain Formation represent a southward-prograding and coarsening-upward marine sequence bed by a braided fluvial system, possibly South Saskatchewan type (Miall 1978). Upward facies transitions represent sedimentary environments ranging from prodelta through deltaslope and foreslope (Rainbird 1985) to tidal flat and channel, overlain by topset set beds indicating braided stream sediments.

Early Proterozoic Nipissing diabase forms an east-trending 700 m thick sill which intrudes mainly lithologies of the Lorrain Formation and the Firstbrook Member of the Gowganda Formation. Contact metamorphism of these sediments has resulted in chlorite spotting in arkoses of the Lorrain Formation and local chloritization, epidotization, and recrystallization of shaley mudstones of the Firstbrook Member.

Coarse-grained quartz diabase and hypersthene gabbro are the main lithologies in the lower 500 m of the diabase sill. Along the lower contact of the sill and where it intrudes laminated shaley mudstones of Firstbrook Member, the diabase is fine-grained, epidotized, and exhibits characteristic polygonal jointing. Local partial or total melting appears to have occurred at several localities along the lower contact along Anima Nipissing Lake.

Coarse-grained varied textured diabase is the main lithology of the upper 200 m of the sill. Granophyre occurs sporadically along the upper contact of the sill where it is in contact with arkoses of the Lorrain Formation.

The youngest Precambrian in the area are represented by dikes of two different lithologies. Northwest-trending dikes of the Sudbury Swarm make up the first type and have characteristic 1 to 2 cm plagioclase phenocrysts and are generally from 20 to 100 m wide. Such dikes are commonly traceable for 1 to 10 km across both Brigstocke and Kittson Townships.

Lamprophyre represents the second type of dikes and consists of a coarse-grained, biotite, and muscovite matrix containing 5 to 30% rounded accidental clasts of Archean, Huronian, and Nipissing lithologies. The vertical dikes are 10 to 30 m wide and generally trend in a northerly direction and occur at Mountain and Anima Nipissing Lakes in Brigstocke Township.

STRUCTURAL AND METAMORPHIC GEOLOGY

Archean plutonic and metavolcanics are generally weakly foliated with a near vertical east-trending fabric. Brittle deformation and brecciation with some associated chloritization and quartz veining occurs locally along several north-northwest-trending shears which transect the Archean basement. Ductile deformation occurs within a 100°-trending mylonite zone (200 m wide) which cuts the Archean plutonic rocks on the eastern arm of Mountain Lake. Minor disseminated pyrite mineralization is associated with this zone.

Sedimentary rocks of the Gowganda and Lorrain Formations are undeformed in most places and have undergone only minor folding during the Penokean Orogeny along several gently plunging (10°), subhorizontal, west-trending fold axes.

Locally extensive, postdepositional breccias occur within the rocks of the Gowganda and Lorrain Formations. The majority of the breccias are confined to vertical to subhorizontal zones comprised of angular 3 mm to 4 cm (3 m maximum) sized sedimentary clasts which show no internal deformation. Numerous local kink bands occur in host rocks of these breccias. The proximity of such breccia zones to Nipissing diabase suggest that uplift during intrusion and/or steam and/or water escape processes were probable causes of the brecciation.

Another type of uncommon breccia consists of subrounded and essential 2 to 4 cm clasts of arkose in a fine-grained sand matrix found at several localities within rocks of the Lorrain Formation. These breccia bodies appear to be vertically oriented and occur as irregular-shaped isolated patches (10 to 30 cm diameter) within the sediments. Elsewhere in the Temagami and Maple Mountain area (Card *et al.* 1973), similar breccias also contain Nipissing diabase fragments. These breccias may represent gas escape features and/or may be related to lamprophyre dikes that commonly occur nearby.

The grade of regional metamorphism in the area varies from unmetamorphosed olivine diabase and lamprophyre dikes (Middle Proterozoic age) to lower greenschist facies in the Huronian sedimentary rocks to amphibolite facies (Winkler 1976) in the Archean metavolcanic and migmatitic/metaplutonic rocks.

ECONOMIC GEOLOGY AND RECOMMENDATIONS FOR FUTURE EXPLORATION

Copper, cobalt, silver, and gold mineralization is related to Nipissing diabase dikes and sills intruding arkoses of the Lorrain Formation and laminated shaley mudstones of the Firstbrook Member (Gowganda Formation).

Located adjacent to the Montreal River in Kittson Township, the Cobalt-Kittson Mine is hosted in a narrow (70 m wide) Nipissing diabase dike cutting arkoses of the lower Lorrain Formation near the Gowganda-Lorrain contact. Chalcopyrite, smaltite, and pyrite occur in several north-trending calcite veins which are vertically oriented and 4 to 100 cm wide. The veins are hosted in a fractured and faulted zone parallel to the vertical diabase dike. Assay results from Johns (1985) indicate 0.08 and 0.20 ounce gold per ton.

During the present mapping project several more samples were taken for chemical investigations.

A similar geological setting occurs approximately 2 km to the south at the Shakt-Davis Mine on the northeastern shore of Kitt Lake. Here several major calcite veins are hosted in a fractured and faulted zone within Nipissing diabase. This zone strikes 060°, parallel to a 120 m thick, vertical diabase dike. The Main Vein varies in width from 1 to 7 m whereas the parallel Chimney Vein is from 1 to 3 m wide. Both are vertically oriented and contain smaltite, cobaltite, gersdorffite, erythrite (cobalt bloom), annabergite (nickel bloom), pyrite, chalcopyrite, and niccolite. Assays in-

dicate 1.5% Co and minor Ag over a width of 1.37 m, with select grab samples indicating up to 4% Co and others with up to 2.72 ounce Au per ton. A further test of hard-cobbed ore indicated values of 0.87 ounce Au per ton, 0.25 ounce Ag per ton, 7.92% Co, and 7.72% Ni (Assessment Files, Resident Geologist's Office, Cobalt). Grab samples collected by the author from the mine dump yielded assay values of 0.10 ounce Au per ton, <0.10 ounce Ag per ton, 2480 ppm Co, 580 ppm Cu, and 7520 ppm Ni (Geoscience Laboratories, Ontario Geological Survey, Toronto).

Sulphide mineralization hosted in calcite, calcite-quartz, and quartz veins within the main Nipissing diabase sill also occurs along its upper contact at several localities in Brigstocke Township. At one such location north of Brigstocke Lake, several vertical, 2 to 4 cm calcite veinlets trend in a southeast direction and contain disseminated smaltite, cobaltite, chalcopyrite, pyrite, ±native bismuth (Todd 1926). Previous prospecting, trenching, and subsequent diamond drilling indicated that little mineralization occurs beneath the trenches. Assay results indicate 2.26% Co, 0.05 ounce Au per ton and <0.10 ounce Ag per ton (Geoscience Laboratories, Ontario Geological Survey, Toronto).

In a similar setting, several minor quartz-calcite veins (2 to 10 cm wide) containing disseminated chalcopyrite, pyrite, and erythrite are hosted in the uppermost part of the sill in Crowrock Bay of Anima Nipissing Lake. Assays from trench grab samples indicate values of up to 7.0% Cu and 0.41% U_3O_8 (Assessment Files, Resident Geologist's Office, Cobalt).

Nipissing granophyre and varied textured diabase of the upper part of the sill are adjacent to metasediments of the Gowganda Formation (Firstbrook Member) at the Island-Kittson Occurrence located at the northwestern corner of Kittson Township on Lady Evelyn Lake. The diabase hosts calcite stringers with disseminated phyrrhotite, chalcopyrite, galena, and sphalerite. Assay results indicate 0.07% Cu, 0.13% Pb, 0.09% Zn, and trace Ni and Co (Card *et al.* 1973).

Scattered and minor sulphide-bearing veins are also hosted in Nipissing diabase at several localities along the lower contact of the sill. A 290°-trending, 15 m adit and 4 m shaft follow a 2 to 4 cm quartz vein with chalcopyrite located on Sugarloaf Island (Anima Nipissing Lake). Assay results indicate values of 1.32 ounce Au per ton, 0.26 ounce Ag per ton, 590 ppm Co, and 580 ppm Cu (Geoscience Laboratories, Ontario Geological Survey, Toronto).

At several locations, mineralization consisting of disseminated pyrite and minor chalcopyrite occurs either within Archean plutonic/migmatitic and mafic metavolcanic rocks or within quartz veins hosted by these lithologies.

In the Mountain Lake area, disseminated pyrite commonly occurs within 100°-trending, pyrite-bearing quartz veins with low assay values of 0.02 ounce Au per ton and <0.10 ounce Ag per ton (Geoscience Laboratories, Ontario Geological Survey, Toronto). Although these showings are minor, further prospecting could result in the discovery of more significant gold or base metal occurrences.

Intense quartz veining is prominent at the Archean-Gowganda Formation unconformity east of the second narrows on Anima Nipissing Lake. These barren veins cut both Archean and Early Proterozoic rocks of the Coleman Member and are thus probably related to the intrusion of Nipissing diabase. This geological environment is analagous to the Cobalt Camp (Legun 1986; Andrews *et al.* 1986) and thus further prospecting and exploration for Cobalt-type mineralization is recommended in the present area.

The three potential areas for finding cobalt, copper, ±silver- and gold-bearing veins are along the upper and lower contact of the main west-trending diabase sill in Brigstocke Township or along several north- and northeast-trending narrow (70 to 140 m wide) dikes in Kittson. The presence of mineralized veins is structurally controlled. The veins occur in parallel fracture zones near margins of the diabase body (dike or sill). As a general rule, values of cobalt, silver, copper, and gold are usually higher in calcite rather than quartz veins. This is more similar to the Gowganda than the Cobalt mining camp.

Some high gold values of more than 1.0 ounce Au per ton are associated with several cobalt-copper showings hosted in Nipissing diabase located in Bigstocke, and Kittson Townships, as well as nearby Cassels and Riddell Townships (Born 1986).

All of these occurrences are good indications of base metal and precious metal mineralization and make the present and neighboring areas promising exploration targets.

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031. Reconnaissance Investigation of the Geology of Yarrow and Doon Townships, District of Timiskaming, with Emphasis on the Huronian Supergroup

R.M. Junnila

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

The map area of Yarrow and Doon Townships covers 187 km^2 and is located 1 km southwest of Matachewan in the District of Timiskaming. The area is bounded by Latitudes 47°50'30"N and 47°50'40"N and by Longitudes 80°39'35"W and 80°55'00".

Access to the central part of the area is by a gravel road which branches southwest from Highway 566, 2 km west of Matachewan. Numerous other gravel roads, plus lakes and rivers, provide good access to all of the area.

The aim of this project was to examine previously unmapped areas of Yarrow and Doon Townships inferred to be underlain by rocks of the Huronian Supergroup. In addition, inliers of Archean metavolcanic, metasedimentary, and plutonic rocks were identified. These, however, were not exhaustively studied.

MINERAL EXPLORATION

The information reported here, if not stated otherwise, is taken from the Assessment Files, Resident Geologist's Office, Kirkland Lake and from the Assessment Files Research Office, Ontario Geological Survey, Toronto.

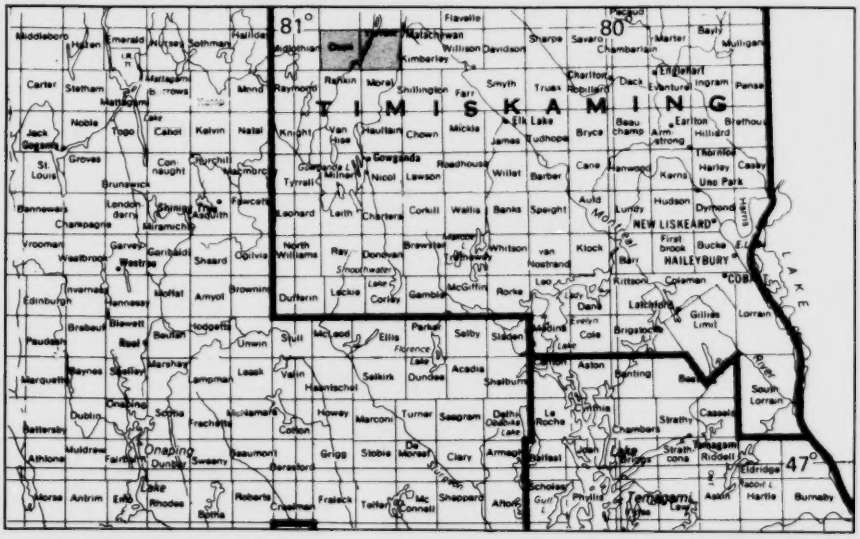
In Doon Township, ground geophysical surveys have been performed in Archean metavolcanic rocks by The Coniagas Mines Limited (1945) and by Canadian Aero Mineral Surveys (1963). In 1964, Laroma-Midlothian Mines Limited drilled one hole to a depth of 121 m in Archean tuffs and syenite porphyry. In 1979, a geochemical soil-sampling program was performed west of Elmer Lake by Bagdad Exploration Associates Limited.

In northwestern Yarrow Township, the Matarrow Mine operated from 1948 to 1952, producing lead from a sheared, silicified, and carbonatized Archean banded iron formation. During the same period, Matarrow Lead Mines Limited drilled 30 holes totalling 2612 m in nearby metavolcanic rocks and banded iron formation. In 1957, Maralgo Mines Limited explored for massive sulphides in a quartz-vein breccia on the southwest shore of Sisseney Lake; twenty-three holes were drilled, totalling 911 m. In 1963, the Barker Mining Syndicate drilled 5 holes totalling 448 m in the course of a gold exploration program in sheared, carbonatized, metavolcanic rocks in north-central Doon Township.

Extender Minerals of Canada Limited currently produces barite from a vein in rocks of the Gowganda Formation on the west shore of the West Montreal River.

GENERAL GEOLOGY

The first geological mapping in the vicinity was by Burwash (1896) along the Nipissing-Algoma survey line. The southern halves of Yarrow and Doon Town-



LOCATION MAP

Scale : 1:1 584 000 or 1 inch to 25 miles

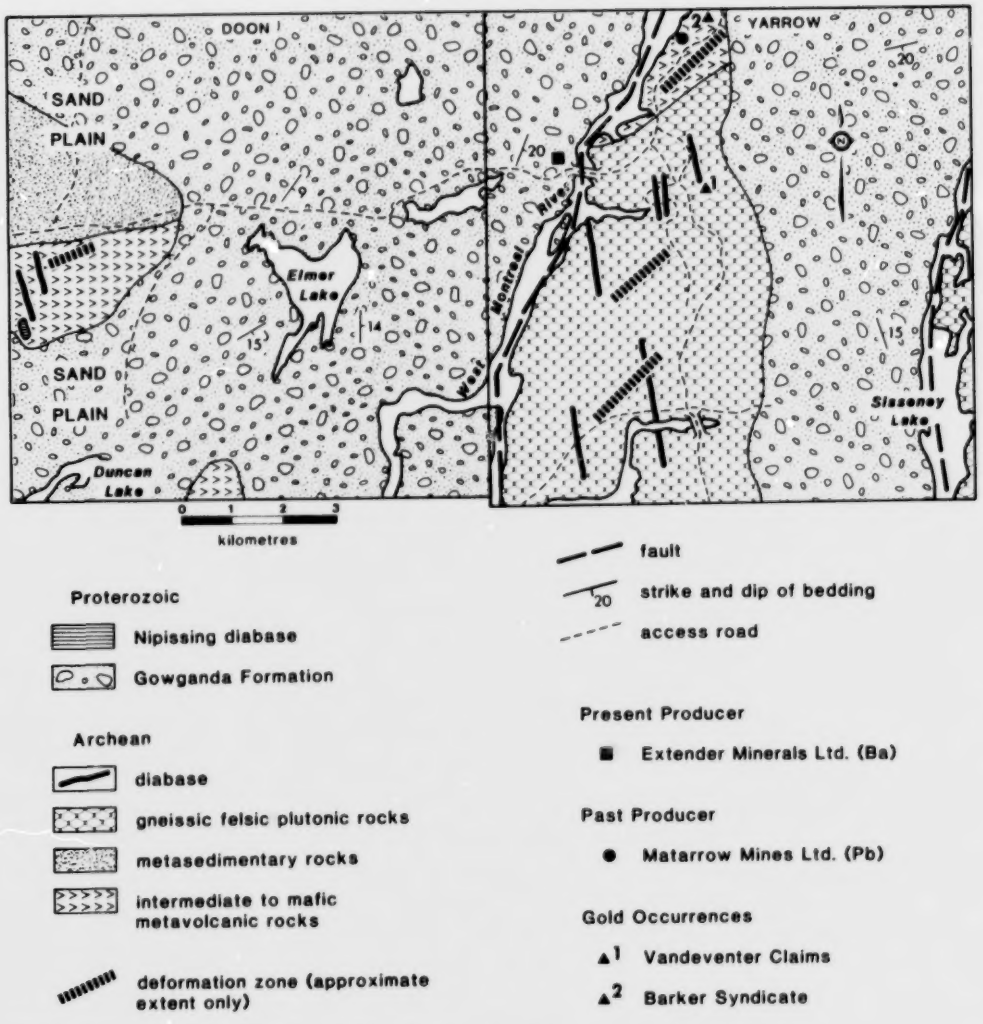


Figure 031.1. *General geology of Yarrow and Doon Townships, District of Timiskaming.*

ships were mapped on a broad reconnaissance scale by Collins (1913). Burrows (1918) mapped northern Yarrow Township on a reconnaissance scale. Cooke (1919) mapped the northern halves of Yarrow and Doon Townships.

The map area is underlain by Archean supracrustal, plutonic, and intrusive rocks, and by Early Proterozoic supracrustal and intrusive rocks (Figure 031.1).

ARCHEAN

Three inliers, within the Huronian rocks of Yarrow and Doon Townships, expose northeasterly striking, northwest-dipping, mafic to intermediate metavolcanic rocks and metasedimentary rocks. In Doon Township, foliated intermediate metavolcanic rocks (flows?) occur east of Duncan Lake. In north-central Yarrow Township, foliated and carbonatized intermediate metavolcanic rocks are exposed. Interbedded with this sequence are two thin, strongly deformed units of banded iron formation. No reliable facing criteria were observed in either of the above areas. West of Elmer Lake, pillowed and amygdaloidal intermediate flows, a flow-top breccia, and tuffs are exposed; the succession here is north-facing.

Archean metasedimentary rocks are exposed west and northwest of Elmer Lake in Doon Township. Exposure in this area is poor due to the presence of an extensive sand plain. The succession consists of diamictite (polymictic paraconglomerate), coarse-grained to pebbly, laminated to cross-stratified sandstone, siltstone, and mudstone. The clast composition of the diamictites is dominated by felsic to intermediate metavolcanic lithologies. Less abundant are clasts of mudstone, chert, and mafic to ultramafic metavolcanic rocks. The matrix is fine- to medium-grained sandstone in which ferroan-carbonate replacement alteration is common. The poor sorting and matrix-supported texture of the diamictites suggest

deposition by debris flows. Interbedded siltstone and mudstone display graded and convolute bedding and were likely deposited by turbidity currents. Sedimentary structures such as cross-stratification and graded bedding indicate that the succession faces northward. The contact with underlying metavolcanic rocks was not observed.

Gneissic felsic plutonic rocks are exposed in the western half of Yarrow Township and form the northwestern margin of the Round Lake Batholith. Massive quartz-phyric granitic rocks of the Round Lake Batholith are exposed on the eastern shore of Sisseney Lake. All of the above have been locally intruded by granitic, pegmatitic, and aplitic rocks.

Several narrow, north and northwest-trending Matachewan diabase dikes intrude the Archean supracrustal and plutonic rocks. The dikes are generally massive, fine grained, and contain small sulphide grains. Some outcrops display plagioclase phenocrysts and in places are glomeroporphyritic.

EARLY PROTEROZOIC

Gowganda Formation

Rocks of the Coleman Member of the Gowganda Formation underlie most of the map area. The reader should note that in the Cobalt Embayment, the Gowganda Formation consists of the basal glaciogenic Coleman Member and the overlying deltaic-marine Firstbrook Member (*see* Rainbird (1986) and Mustard and Donaldson (1987) for a discussion of these members). The formation rests unconformably on the Archean basement and ranges up to 250 m in thickness, forming prominent hills. Strata generally strike to the northeast and dip 10° to 20° to the southeast; variations occur due to local faulting. The basal rock type in the study area is massive to faintly laminated siltstone with rare granitic pebbles. This is succeeded by laminated to finely bedded mudstone, siltstone, and pink-weathering, fine-grained sandstone. The sandstone may occur as thin beds or small lenses and commonly displays features of soft-sediment deformation such as contorted bedding and ball-and-pillow structures. Associated with these units is laminated to wavy-bedded siltstone and mudstone. This unit contains dropstones: these are isolated clasts, mainly of granitic composition, which range in size from a few millimetres to a maximum of 60 cm. The clasts deform underlying laminae, and are draped by overlying laminae.

The remainder of the succession is a heterogeneous assemblage of interbedded sandstone, diamictite (polymictic paraconglomerate), and siltstone. No apparent cyclicity was observed in these rocks. The bedding thickness of these units ranges from 30 cm to 3 m, with an average of 1 m. Sandstones vary from fine to very coarse grained and are typically massive. Some of the coarser-grained sandstones display parallel lamination along with scour structures and mudstone rip-up clasts. Chaotic folding, contorted bedding, and partial homogenization of bedding are common. No cross-stratification was observed. The sandstones are typically pink due to hematite staining. Coarse-grained and pebbly varieties, however, appear to be the reconstituted debris of granitic rocks rich in potassium feldspar. A less common variety of sandstone is dark grey in colour, fine to medium grained, and massive.

The diamictites are unstratified and consist of rounded to angular clasts in a matrix of siltstone to fine-grained sandstone. The clasts are mainly pink granitic rocks, most notably a coarse-grained, quartz-phyric type. Less abundant are clasts of mafic to intermediate metavolcanic rocks, schist, diabase, and vein quartz. Clast size ranges from a few millimetres to 90 cm. The average clast is 3 cm in diameter. Loading of underlying beds was observed at the bases of some diamictite units.

Siltstone is the least common rock type in the upper part of the succession. It is commonly parallel-laminated to wavy-bedded; crosslamination is rare. Bedding thickness ranges from 10 cm to 1 m, with an average of 20 cm.

Huronian rocks younger than the Coleman Member of the Gowganda Formation are not present in the map area.

DEPOSITION ENVIRONMENT

Deposition of the Gowganda Formation in the study area was dominated by resedimentation processes which deposited material in relatively deep water. The poorly-sorted, matrix-supported diamictites lack grading and stratification and are comparable to Walker's (1975) disorganized-bed model. Deposition of this type of bed is attributed to debris flows. Massive to laminated sandstones, which display evidence of scouring (erosion surfaces, rip-up clasts), and soft-sediment deformation (contorted bedding, chaotic folding) were deposited rapidly by fluidized flow or grain flow (Howell and Normark 1982; Miall 1983). The finely interbedded mudstone and siltstone near the base of the succession were deposited from suspension whereas thin sandstone beds represent turbidity flows. The presence of soft-sediment deformation indicates the instability of rapidly deposited water-saturated sediment. Weak traction currents acted on silt and fine sand to produce small lenses.

Dropstones, which indicate ice-rafting of debris, are the only evidence in the area pointing to a glaciomarine environment of deposition. No reliable paleocurrent indicators were found. The study area lies to the south of a narrow north-trending outcrop area of the Gowganda Formation which transects Archean strata south of Timmins. This north-trending zone has been interpreted as a paleovalley system. Given the general north to south sediment transport direction in the Gowganda Formation, the source area for some of the debris in the study area may lie to the north near Timmins.

A succession similar to that described above was observed by Miall (1983) in drill core from Fallon Township, which lies approximately 35 km north of the present study area. Based on the abundance of dropstones and the presence of undoubtedly subaqueous sediments, Miall (1983) proposed a glaciomarine environment of deposition. Diamictites are interpreted as tills reworked by subaqueous debris flows in a proximal glaciomarine environment. Sandstones were deposited as subaqueous outwash lobes

in a distal glaciomarine environment. Sedimentation of the finer-grained units is attributed to rainout from floating ice, deposition by distal turbidites, and reworking by rare traction currents. The preliminary results of the present study support these interpretations. As Miall's (1983) study was based on drill core, which provided only one cross-section through the succession, any indications of paleocurrent direction were found to be equivocal.

Nipissing Diabase

A few isolated outcrops of Nipissing Diabase occur in western Doon Township. The identification of these rocks as Nipissing Diabase is tentative and is based on the presence of "varied texture" which consists of pegmatitic gabbro pods set in a fine-grained gabbro matrix. This texture is typical of Nipissing diabase bodies in the Cobalt area.

PLEISTOCENE

Glaciofluvial deposits form a sand plain which covers most of the western quarter of Doon Township. A large parabolic dune occurs north of Duncan Lake in the southern portion of the sand plain. Sizeable areas of ground moraine are found in northeastern Doon Township.

STRUCTURAL GEOLOGY

The reconnaissance nature of this study did not permit a thorough examination of the structural geology of the Archean rocks of Yarrow and Doon Townships. In addition, the metavolcanic and metasedimentary rocks are poorly exposed. In both Yarrow and Doon Townships, the rocks possess a northeast-trending foliation, which dips steeply to the northwest. This foliation is parallel to bedding planes in the metasedimentary rocks.

The gneissic felsic rocks of the Round Lake Batholith in Yarrow Township, also possess a northeast-trending foliation which dips steeply to the northwest. Within the gneissic rocks there are discrete areas of intensely deformed to mylonitized migmatitic rocks. The horizontal component of shearing in these rocks is left-lateral. It is emphasized that these zones were not traced out in detail. Two major northeast-trending faults occur in Yarrow Township and are expressed by the West Montreal River and by Sisseney Lake. Both faults separate the Gowganda Formation from Archean plutonic rocks of the Round Lake Batholith. Fault movement appears to have been mainly vertical.

Northeast- and northwest-trending joint sets occur in the Gowganda Formation. Local variations in strike and dip indicate post-depositional block faulting.

ECONOMIC GEOLOGY

ARCHEAN INLIERS

Although economic concentrations of gold have not yet been found in Yarrow and Doon Townships, the area warrants future exploration. The Archean rocks are affected by shearing which may represent a westerly extension of the Kirkland Lake-Larder Lake Fault Zone. Two past producers of gold are located immediately adjacent to the study area: the Young-Davidson Mine in Powell Township, and the Stairs Mine in Midlothian Township. The latter is currently being re-evaluated by Goldteck Mines Limited.

HURONIAN SUPERGROUP

The Huronian Supergroup has recently been studied for its potential to host Witwatersrand-type paleoplacer gold deposits (Long and Leslie 1982; Mossman and Harron 1984). The favourable sites for such concentrations are in the deposits of braided streams in an alluvial fan setting (Mossman and Harron 1984), and possibly in glacio-fluvial outwash deposits (Long and Leslie 1982). Fluvial and glacio-fluvial strata were not observed in the course of this study and hence the prospects for placer gold concentrations in Yarrow and Doon Townships are poor. Knowledge of depositional environments and gold concentration in the study area may, however, be useful in gaining a better understanding of sedimentation and gold distribution in younger Huronian strata.

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032. Regional Sedimentology of the Lorrain Formation (Aphebian), Central Cobalt Embayment

Randy J. Rice

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

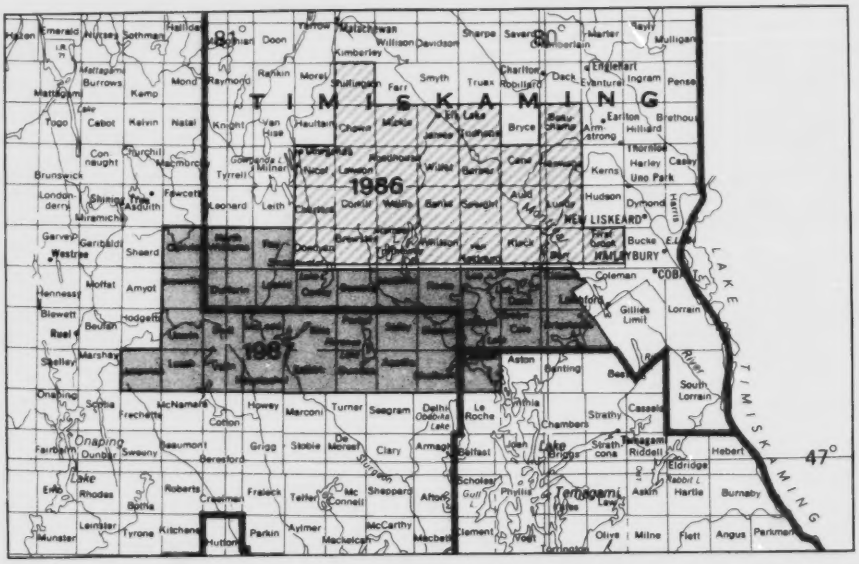
INTRODUCTION

A three-year project was started by the Ontario Geological Survey in 1986 to evaluate the paleo-placer gold potential of the Lorrain Formation (Aphebian) throughout the Cobalt Embayment of central Ontario. The study was prompted by anomalous gold values (up to 1.2 ppm) found in hematitic sandstone and quartz pebble conglomerate in the northwest portion of the Cobalt Embayment (Colvine 1981, 1983). To facilitate this evaluation, a regional sedimentologic study of the formation was undertaken by the author to determine the depositional environment(s) in which the Lorrain detritus accumulated. A fluvial and/or beach environment would favour the economic accumulation of detrital gold, if it were present, in the depositional system. Deposition in a marine environment, such as a continental shelf, would result in the broad, non-economic dispersal of detrital gold due to the presence of interacting current regimes (longshore drift, tidal currents, wind-driven open shelf currents, turbidity currents). The determination of the environment(s) of deposition is therefore crucial to the evaluation of the paleo-placer gold potential of the formation. Hadley (1968) interpreted the Lorrain Formation to represent deposition in a shallow marine to beach environment, while Long and Colvine (1985) suspected that the majority of the formation might represent deposition in a sandy, braided, fluvial environment.

Results of field work conducted during 1986 are given in Rice (1986), along with a thorough introduction to the project. This report summarizes observations made during the 1987 field season and also presents 1986 analytical data (gold values) which were not available for inclusion in Rice (1986).

The area investigated during the 1987 field season (location map) is located south of the 1986 field area. As a consequence of this more southerly location in the Cobalt Embayment, the majority of the exposures examined in 1987 were of the upper quartz arenite member (Collins 1917) of the Lorrain Formation. This member characteristically weathers white which, in combination with its compositional homogeneity, commonly makes the recognition of sedimentary features difficult. The basal, feldspathic arenite member of the formation was only encountered at the beginning and end of the 1987 field season, in the west and east of the study region, respectively.

It is well known that, due to its greater specific gravity, gold will be deposited with coarser grained detritus of lower density (e.g. quartz gravel) or found associated with detritus of higher density (eg. heavy mineral lags). If the Lorrain Formation represents a fluvial deposit, placer gold should, therefore, be found with basal channel-fill gravels or with heavy mineral lags. While heavy mineral lags were relatively common in the basal feldspathic arenite member of the Lorrain Formation, encountered frequently during the 1986 field season, they were only rarely noted in the upper quartz arenite member in both the 1986 and 1987 field seasons. For this reason, a



LOCATION MAP

Scale : 1:1 584 000 or 1 inch to 25 miles

Photo 032.1. The contact between the interstratified siltstone and sandstone constituting the Firstbrook Member of the Gowganda Formation and the overlying coarse-grained feldspathic arenite composing the basal member of the Lorrain Formation along Highway 560. The Jacobs staff is approximately 1.5 m in length. The lithological contrast across this contact is reduced in the eastern portion of the central Cobalt Embayment.

priority for the 1987 season was the location of gravel grade detritus which could be interpreted as basal channel-fill deposits.

SUMMARY OF OBSERVATIONS

BASAL FELDSPATHIC ARENITE

Lithology

The basal member of the Lorrain was examined in two areas:

1. on the northern portion of a power line running southwards through North Williams, Dufferin, Stull and Valin Townships, along the western margin of the 1987 field area, and
2. in the Lady Evelyn Lake-Diamond Lake region, specifically in Dane, Leo, Medina and Canton Township, near the eastern margin of the 1987 field area.

The lithological contrast between the underlying Firstbrook Member of the Gowganda Formation and the basal Lorrain Formation differs in these two areas. In the west, the basal Lorrain is similar to the excellent exposures which exist along Highway 560, between the towns of Elk Lake and Gowganda. While the contact with the Firstbrook Member was not observed along the power line, it is exposed along Highway 560. In this region, the Firstbrook Member consists of thinly interstratified (centimetres to decimetres), maroon weathering, laminated to ripple laminated, coarse siltstone and pale brown to maroon weathering, rippled to non-stratified, very fine-grained arenite. In sharp contrast, the basal Lorrain is a pale pink weathered, coarse-grained, feldspar-rich (subarkose to arkose) arenite (Photo 032.1). Where exposed, the contact is gradational. In the Lady Evelyn-Diamond Lake region, this lithological contrast is reduced. The uppermost Firstbrook Member may be either the interstratified siltstone and arenite described above or what is interpreted to be a subaqueous slump unit, varying from 2 to 4 m in thickness and displaying large load (ball and pillow, pseudonodule) and soft sediment brecciation features. The basal Lorrain gradationally overlies both of these lithologies and consists of a buff weathering, grey, rippled to non-stratified, locally feldspathic, very fine to fine-grained arenite. Where the Lorrain overlies the interstratified siltstone and arenite, the contact is identified simply by the loss of siltstone.

The essential difference between the basal Lorrain in the Lady Evelyn-Diamond Lake region and the rest of the Cobalt Embayment examined to date is, therefore, a reduction in both grain size and feldspar content.

While gravel grade detritus (granule-pebble) is present along the northern portion of the power line in the west of the study area, it occurs only as small (centimetres to decimetres), local pockets which are not basal channel-fill lag deposits. Similar pockets of gravel grade material were identified in the basal Lorrain to the north (Rice 1986). Heavy mineral lags are also reasonably common in the 1987 area.

Lithofacies Arrangement

A consistent lithofacies arrangement for the Lorrain Formation was reported in Rice (1986), consisting of crudely tabular, coarser grained, sandstone bodies, usually decimetres to several metres in thickness, separated by lensoid horizons of usually greenish weathering, more micaceous, finer grained sediment (coarse siltstone to very fine grained arenite) several centimetres to several tens of centimetres in thickness. The contact between the finer grained lens and the coarser grained, overlying sandstone body is predominantly erosional. The basal contact can show a small amount of reworking but is mainly sharp to gradational. Consequently, these horizons are considered to be finer grained capping units (FCU) to the underlying sandstone body. The basal Lorrain examined during the 1987 field season exhibited the same lithofacies arrangement. Sedimentary features dis-

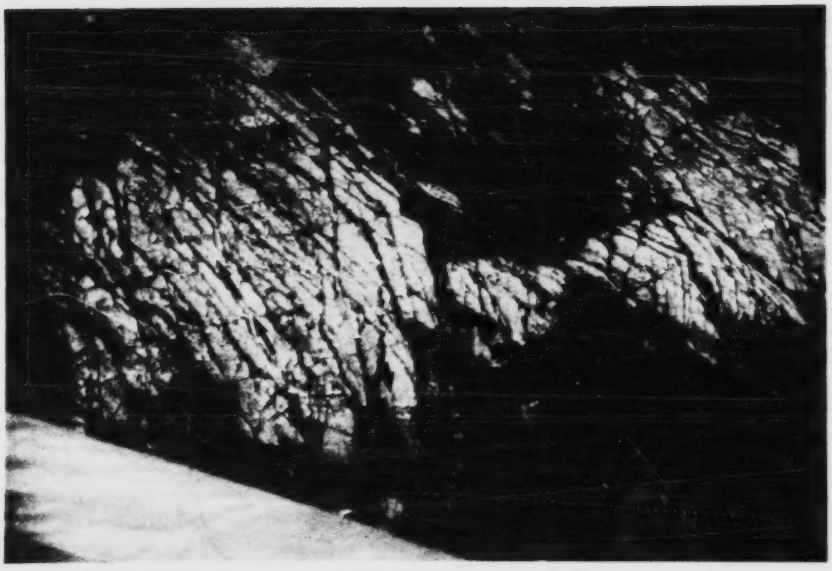


Photo 032.2. *Quartz pebble conglomerate horizons (arrows) in the upper member of the Lorrain Formation at the southwestern extremity of Welcome Lake in northwestern Valin Township. The horizons contain, at the most, only several layers of quartz pebbles. The curvilinear nature of one horizon (shorter arrow) indicates that occasional, small, channelized flows did occur. A portion of the Zodiac in the lower left corner of the photograph and the small plant on the outcrop provide the scale.*

played by the coarser grained sandstone bodies are similar to those observed during the 1986 field season. These include occasional, large (up to several metres) sets of planar tabular and trough cross-bedding, ripple cross-lamination, normally graded horizons, pockets of granule to pebble grade detritus and heavy mineral laminae.

UPPER QUARTZ ARENITE

Lithology

The majority of the outcrop examined during the 1987 field season belonged to the upper quartz arenite member of the Lorrain Formation. While the lithology of this member is consistent across the central Cobalt Embayment, areal variation in sandstone grain size and, rarely, weathered colour does occur. This member is effectively entirely weathered white/greenish-white. The only exception found occurs on a small island in the northern portion of Welcome Lake in Valin Township. At this location, which is stratigraphically close to the unexposed contact with the overlying Gordon Lake Formation, the upper member displays both purple and white weathering colours. The coarser grained sandstone bodies (*see* below and Rice (1986)) of the upper member of the formation are usually fine to medium grained but a significant amount of local variation does occur. The maximum areal variation in grain size range noted for these bodies is fine sand to pebble grade detritus.

The sedimentary structures observed in the upper member of the Lorrain Formation during the 1987 season are similar to those described in Rice (1986). These include: a. occasional large scale (several metres), planar tabular and trough cross-bedding; b. common smaller scale (several decimetres), planar tabular and trough cross-bedding; c. ripple cross-lamination; d. normally graded units, usually 10 to 15 cm thick; and e. pockets of granule to pebble grade detritus. While rare large channel scours were reported from this member in Rice (1986), this feature does not occur in any of the upper member exposures examined in 1987. The only instance of large scale (10 to 30 cm) sets of chevron cross-bedding found by the author in this member occur in an island outcrop on Welcome Lake in Valin Township.

Granule to lower pebble grade detritus is most abundant in the upper member along the power line running southwards along the western margin of the 1987 field area. However, the coarsest grade of gravel size detritus (mid-pebble range) found by the author occurs in a quartz pebble conglomerate at the southwestern extremity of Welcome Lake in northwestern Valin Township (Photo 032.2). The granule to lower pebble grade detritus is not plentiful in the discontinuous outcrop along the power line. At this location, as well as on Welcome Lake, the quartz clast conglomerate occurs only as isolated lenses in the coarser grained sandstone bodies (*see* discussion of lithological arrangement). The lenses are a maximum of 50 to 60 cm thick and have a lateral extent of at least several metres. Pebble grade quartz clast conglomerate lenses only occasionally occur in the upper member of the Lorrain Formation in the remainder of the central Cobalt Embayment.

Lithofacies Arrangement

The upper member of the Lorrain Formation examined during the 1987 field season exhibits the same arrangement of lithofacies displayed by the lower member (Photo 032.3). This situation was also reported for the northern Cobalt Embayment in Rice (1986). The FCU separating the coarser grained sandstone bodies in the upper Lorrain are commonly not as weathered green as those in the basal member, often exhibiting a pale grey or tan weathering colour. They also are somewhat finer grained, containing principally silt-size detritus, and contain very

Photo 032.3. *The lithofacies arrangement displayed by the upper member (white orthoquartzite) of the Lorrain Formation. A portion of the Welcome Lake section included in Figure 032.1 is shown in this photograph. Arrows mark the position of some FCU only several centimetres thick. FCU and/or amalgamation surfaces are the only way to distinguish stratigraphic units in these sections. The trees in the left of the photograph provide the scale.*

little or no micaceous minerals. Their abundance in the upper member is variable. At some locations they have been largely removed during the erosional emplacement of the overlying sandstone body. In such cases, the sandstone bodies are separated only by an amalgamation (erosion) surface. At other locations, especially fault scarps, the finer grain size of the capping units has resulted in them serving as the loci of small amounts of movement. Under such circumstances, they are commonly sheared out. However, where they survive, their identification is often made significantly easier by their preferentially acquiring a cleavage. The scale of the FCU in the upper member is similar to that reported in Rice (1986); their maximum thickness usually varies between 5 and 20 cm and their maximum lateral extent is often only several metres due to the erosional emplacement of the overlying sandstone body.

Stratigraphic sections in the upper member were measured at well-exposed fault scarps throughout the central Cobalt Embayment. Several of these are presented in Figure 032.1. Their similarity reflects the consistent lithofacies arrangement exhibited by the upper member.

Paleocurrent Analysis

As mentioned above, sedimentary structures are difficult to see in the white weathered quartz arenite which characterizes the upper member due to the absence of distinct compositional or textural breaks. In addition, many cross-sets do not reveal the third dimension of their foresets and therefore cannot be measured. As a result of the above factors, only 79 measurements of planar tabular cross-strata were obtained from the upper member in 1987. Their distribution is shown in Figure 032.2. Within the context of this small data base, a weak preferred orientation southwards is indicated, with several locations displaying a bi-polar, nearly opposed, pattern.

DISCUSSION

The possibility that the Lorrain Formation represents a siliciclastic shelf deposit was raised in Rice (1986). This was based on a genetic hypothesis that the author had developed during the course of the 1986 field season. The essential component of this hypothesis is the rare presence of large (10 to 25 cm amplitude, 15 to 40 cm wavelength), symmetrical waveforms along the upper surface of the FCU. These structures are interpreted to indicate that deep water, wave generated, oscillatory currents reworked the upper surface of the finer grained sediment during or prior to the deposition of the overlying coarser grained sandstone body. Additional symmetrical waveforms of this scale were not observed in the outcrop examined during the 1987 field season. The low preservation potential of these structures in an above-fair-weather wave base shelf setting, combined with the observation of only part of the available exposure (due to the regional nature of the project), is suggested to account for this. Lack of these structures in the area examined in 1987 is not considered to be strong evidence against a shelf hypothesis. Additional symmetrical waveforms of this scale were found, during the 1987 season, in an exposure of the basal member of the formation chosen for detailed work from the 1986 study area to the north.

Exactly the same lithofacies arrangement observed throughout the Lorrain Formation during the 1986 season in the northern Cobalt Embayment is present across the central Cobalt Embayment in the basal through upper member of the Formation. For this reason, the author's original hypothesis (Rice 1986) of a marine depositional setting is retained, as opposed to the sandy braided fluvial interpretation which has been suggested by other workers (Long and Colvine 1985).

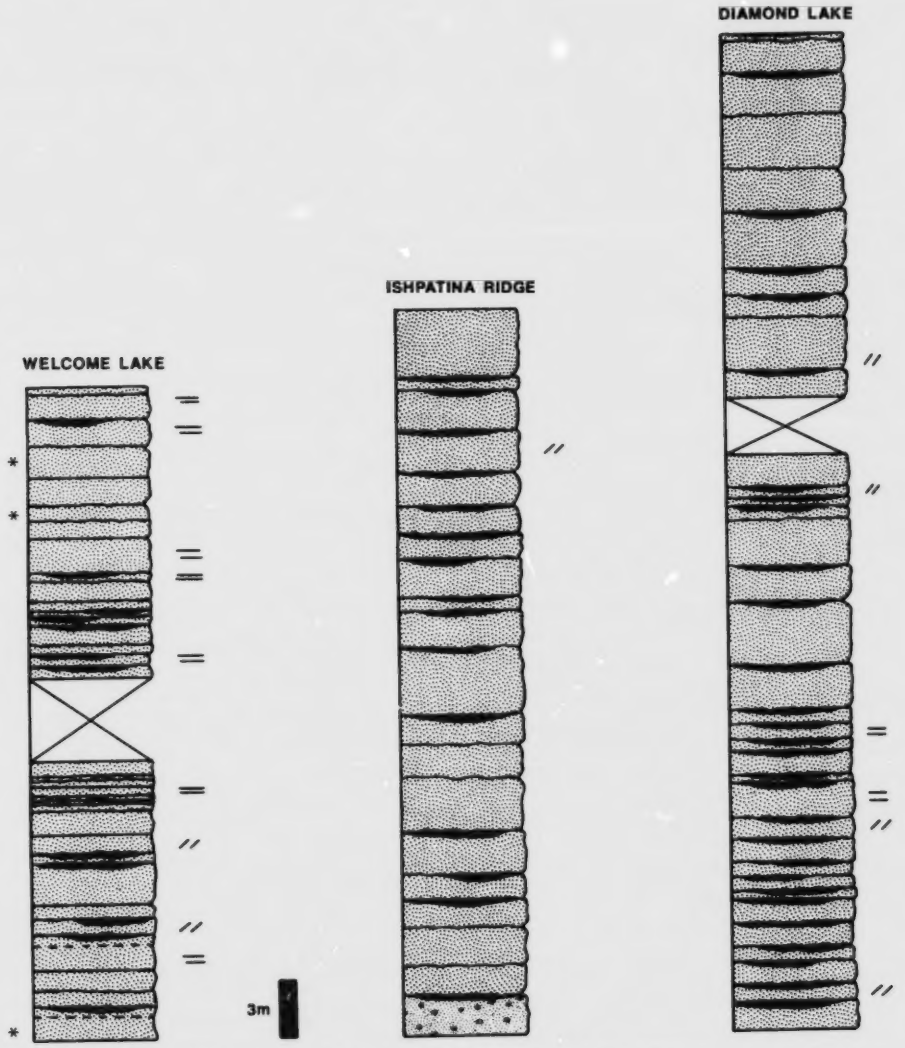


Figure 032.1. *Lithofacies arrangement in selected sections of the upper member (white orthoquartzite) of the Lorrain Formation in the central Cobalt Embayment. Welcome Lake section-northwestern Valin Township, Ishpatina Ridge section-southwestern Corley Township, Diamond Lake section-southwestern Medina Township. Note the consistency in the style of lithofacies arrangement. This arrangement is displayed by the upper member throughout all of the Cobalt Embayment examined to date. A precise correlation of the sections within the upper member is not implied.*

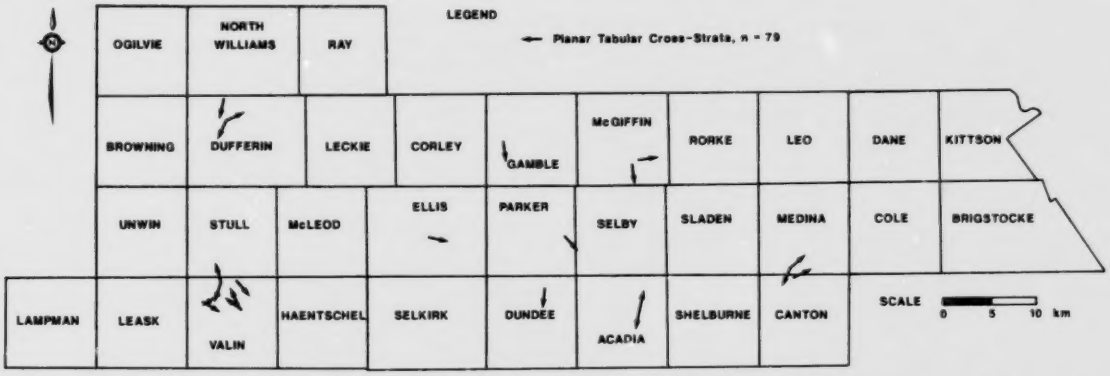


Figure 032.2. *Paleocurrent data (planar tabular cross-strata only) from the upper member (white orthoquartzite) of the Lorrain Formation in the central Cobalt Embayment. The arrows represent either single measurements or the vector mean of a number of measurements at a given location. Both directions are shown at those locations where a bi-polar pattern is suggested by the data. Structural tilt has been removed.*

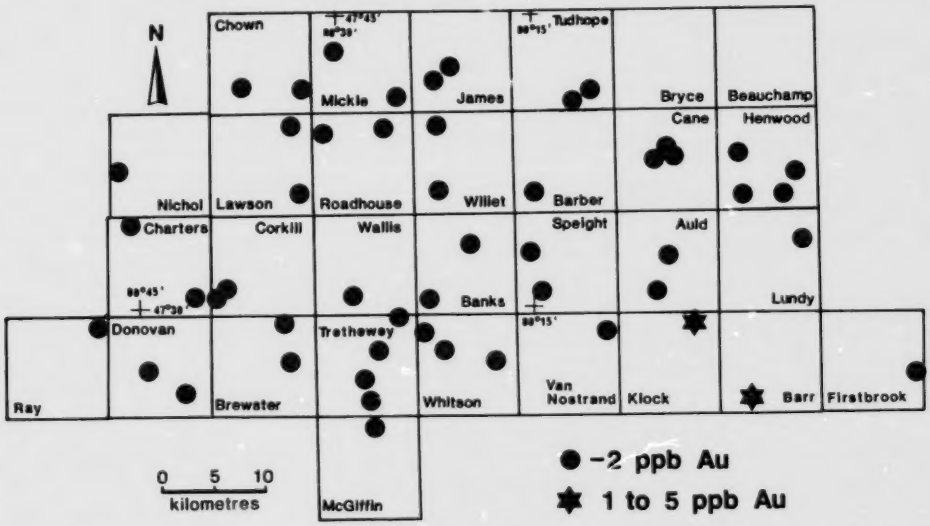


Figure 032.3. *Gold values obtained from the analysis of Lorrain sandstone and conglomerate collected in the northern Cobalt Embayment during the 1986 field season. Analyses were performed by the Geoscience Laboratories, Ontario Geological Survey, Toronto.*

LABORATORY RESULTS

Gold values from Lorrain Formation exposures examined during the 1987 field season are not yet available. The results of analysis of samples from the 1986 study area by the Geoscience Laboratories, Ontario Geological Survey, Toronto, are presented in Figure 032.3. As indicated by this figure, all samples from the northern Cobalt Embayment returned gold values which were less than or equal to 5 ppb. It must be stressed, however, that all but two of these samples are Lorrain sandstone which, as discussed above, is not as favourable a site for the accumulation of detrital gold as conglomerate.

ACKNOWLEDGMENTS

Very capable and responsible field assistance was provided by Derrick Watson, fourth year geology student at the University of Ottawa. Peter Born of the Ontario Geological Survey and Geoff Burbidge, Ph.D. candidate at the University of Ottawa, are thanked for their introduction to the Gowganda and Lorrain Formations in the Anima-Nippissing Lake area. Warren Evershad, Ministry of Natural Resources, Temagami, is thanked for permission to travel the Deep Lake road.

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Grenville Province

033. Grenville Province Studies

R.M. Easton

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Many of Ontario's first mines were located in the Grenville Province, and in the past few years, a resurgence of exploration activity has occurred in the Grenville, particularly for gold, and a variety of industrial minerals such as graphite, talc, and wollastonite. However, although easily accessible, much of the Grenville Province remains unmapped in detail (scales of 1:50 000 or less). To assist metallic and non-metallic mineral exploration in the Grenville Province, the Ontario Geological Survey's program is three-fold: a) it involves detailed mapping at 1:15 840 in selected areas, with priority given to areas of greatest mineral potential or exploration interest, b) production of 1:50 000 scale compilation maps, particularly in the Central Metasedimentary Belt, and c) detailed studies to address specific problems or to develop models to assist in mineral exploration. Over the next few years, emphasis will be given to the preparation of 1:50 000 scale compilation maps for the Bancroft and Elzevir Terranes of the Central Metasedimentary Belt; a review of lithostratigraphic nomenclature and a compilation of geochemical data in preparation of the Geology of Ontario volume, and continuation of COMDA-funded mapping in the Parry Sound region.

The 1987 mapping program included projects of all three types. Mapping at 1:15 840 scale was started in the Darling area in eastern Ontario by R.M. Easton and E.A. DeKemp (article 034, this volume) in order to better understand the regional geologic setting of gold deposits in the area and to allow preparation of a 1:50 000 scale compilation map of the Clyde Forks Sheet (NTS 31F/2). Their mapping shows that the gold deposits, although hosted in the Robertson Lake Mylonite Zone, are only found associated with mylonites derived from the Lavant Gabbro Complex. Faulting associated with the Ottawa-Bonnechere Graben, and late Precambrian weathering, may also have been important in concentrating gold. They also found high, light rare-earth element contents in magnetite ore from the former Radenhurst-Caldwell iron mine, the second such magnetite-REE occurrence in the Central Metasedimentary Belt.

In the Minden area, a mapping and geochemical study was done by R.M. Easton (article 035, this volume) on some Sr-Y-Zr-Nb enriched rocks, a study following from a detailed mapping project (1:15 840) conducted in the Minden area by the Ontario Geological Survey from 1983-1986 (Easton 1985, 1986a, 1986b, 1987). The work reported in this volume suggests that remnants of an alkaline igneous/volcanic complex may be partly preserved in the area, and that carbonatites may be preserved within the Grenville Supergroup. This work also assists in the 1:50 000 compilation of the Minden Sheet (NTS 31D/15).

G. DiPrisco (article 037, this volume), as part of a project funded by the Canada-Ontario Mineral Development Agreement, continued his examination of the Precambrian-Paleozoic unconformity in the western Grenville Province. He has shown that locally, extensive weathering of the Precambrian land surface occurred before limestone deposition in the early Ordovician; weathering which resulted in local mineral enrichment, including gold. DiPrisco (article 037, this volume) also shows that deposits immediately overlying the Precambrian carry signatures of Precambrian mineralization, and can be used to explore for mineralization along the contact.

In contrast to the better mapped Central Metasedimentary Belt, little detailed mapping is available for the Central Gneiss Belt. In order to help rectify this situation, as part of the Canada-Ontario Mineral Development Agreement (COMDA), a 3-year bedrock mapping project (1:15 840 scale) in the northern part of the Parry Sound Domain was begun in 1986 (Bright 1986). This work was continued in 1987 by G.D. McRoberts and M.L. Tremblay (article 036, this volume). They show that the units mapped in 1986 can be traced to the north, that the Parry Sound Shear Zone is a complex deformation zone involving rocks of both the Parry Sound and Britt Domains, and that the Parry Sound Domain contains numerous small-scale deformation zones. Non-metallic minerals in the area have the greatest potential for development. Related projects under the COMDA program include a study of industrial minerals in the Parry Sound Region (Marmont and Johnston 1987; Marmont and Johnston, article 053, this volume) and a study of the surficial geology (Kor, article 062, this volume). When completed in 1988-89, these programs will allow a better evaluation of the mineral resources of this part of the Central Gneiss Belt.

In addition to the Precambrian Geology Section programs in the Grenville Province described here, several industrial mineral studies conducted by the Resident Geologist and Regional Specialist Offices in 1987 are outlined in the Industrial Mineral Section of this volume.

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034. Darling Area, Lanark and Renfrew Counties

R.M. Easton[1] **and E.A. DeKemp**[2]

[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Geologist, R.R.7, Fallowfield, Ontario.

INTRODUCTION

The Darling area is located 80 km west-southwest of the City of Ottawa, and includes parts of Bagot, Blithfield, Darling, and Lavant Townships. The Village of Lanark lies 17 km southeast of the southeastern corner of the map area, and access is provided by Highway 511 which transects the map area. Additional access is provided by county, township and cottage roads, as well as an abandoned Canadian Pacific right-of-way (the K and P trail) and numerous logging roads. Extensive till cover is present in the northwestern part of the map area, obscuring bedrock geology. Mapping was undertaken in order to better understand the geologic setting of gold deposits in the areas, to study the Robertson Lake Shear Zone, and to investigate low metamorphic grade rocks in the area.

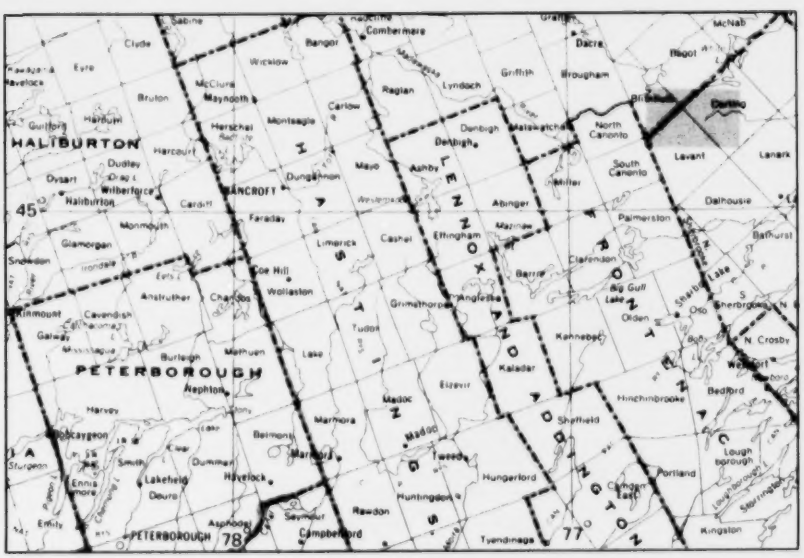
MINERAL EXPLORATION

The history of mineral exploration and production in the Darling area dates back to the 1890s when massive magnetite ore was extracted from the Darling (lots 20 and 22, concession IV and V; lots 21 and 22, concession III, Darling Township), Radenhurst-Caldwell (lot 22, concession III, Lavant Township), and Yuill (lot 25, concession V, Darling Township) Iron Deposits. Shortly afterwards, the Blithfield Pyrite Mine (lots 1 and 2, concession I, Blithfield Township) was developed, and between 1915 and 1930 over 6000 tonnes of pyrite ore was produced for sulphuric acid production (Carter *et al.* 1980).

A number of Au-Cu-Sb deposits in the area, located along the Robertson Lake Shear Zone and including the Little Green Lake (lot 22, concession II, Darling Township), Darling (lot 23, concession IV, Darling Township), and Bradford's Creek (lot 23, concession V, Darling Township) Deposits, have been explored sporadically since 1957 by several companies and individuals, including A.F. Taylor, A. Murray, J. Rankin, Siscoe Metals of Ontario Limited, and Selco Mining and Development Limited (now Selco Mining and Minerals Division, BP Canada Incorporated)(Carter *et al.* 1980; Assessment Files Research Office, Ontario Geological Survey, Toronto (AFRO)). Since 1984, Gleeson-Rampton Explorations Limited have explored extensively along the Robertson Lake Shear Zone (AFRO), and have identified a number of additional gold prospects within the map area (AFRO, Figure 034.1). In addition, they have demonstrated that till geochemistry is an effective exploration tool within the map area (AFRO, Rampton *et al.* 1986).

In addition to gold, exploration for copper mineralization by Canadian Occidental Petroleum Limited took place in 1977 in the Bagot Lake area (AFRO). Carter *et al.* (1980) summarize the geology and development history of most iron, gold, and base metal deposits in the map area (Figure 034.1). Geological Data Inventory Folios (GDIF) are available for Bagot (OGS 1984a) and Blithfield Townships (OGS 1984b).

Two stone quarries have operated in the past, adjacent to the southeastern corner of the map area (Figure 034.1). The Tatlock Omega (Blue) Marble Quarry operated between 1962 and 1971 producing blue, white, pink, and buff-coloured marble for decorative stone and terrazzo uses (Storey and Vos 1981a). Between 1963 and 1971, Anglestone Limited



LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

operated a marble quarry 750 m southwest of the blue marble quarry (Storey and Vos 1981a). Since 1977, this area has been the site of a large quarry operation which supplies white crushed marble (95-97 brightness) to the Steep Rock Resources Incorporated calcite plant in Perth, Ontario, for use in fine and ultra-fine calcite products. A third quarry operated in the map area on Highway 511 at Marble Bluff (Figure 034.1) in a serpentinized marble band, but produced very little stone (Peach 1958). Other reported industrial minerals from the area are marl and talc (Storey and Vos 1981b).

GENERAL GEOLOGY

INTRODUCTION

The Darling area is underlain by Precambrian rocks of Middle to Late Proterozoic age which form part of the Central Metasedimentary Belt (Elzevir Terrane) of the Grenville Province. A few patches of basal Paleozoic deposits and post-Precambrian regoliths are present in the map area (Figure 034.1), and are similar to rocks further east in the Madoc area (DiPrisco 1986). Late Paleozoic faults related to the Ottawa-Bonnechere Graben System cut through the map area.

Precambrian rocks in the area are separated into an eastern and a western domain by the Robertson Lake Mylonite Zone (RLMZ) (Figures 034.1 and 034.2). The eastern domain is characterized by a package of mafic flows and pyroclastic rocks, and dolomitic and calcitic marbles, all intruded by gabbro, diorite, and tonalite of the Lavant Gabbro Complex. Folding in the eastern domain is tight. Rocks in the eastern domain are generally preserved at lower amphibolite facies, but locally middle to upper greenschist facies rocks are present (Figure 034.2). The eastern domain is cut into a number of structural blocks by late Paleozoic faults (Figure 034.2).

The western domain is characterized by a package of mafic, intermediate, and felsic volcanic rocks, metasediments of predominantly volcanic provenance, and dolomitic and calcitic marbles. These rocks are now preserved at middle to upper amphibolite facies (Figure 034.2), and are considerably more deformed than rocks east of the RLMZ. Folding in the western domain is tight to isoclinal. In the extreme western part of the area, the volcano-sedimentary sequence is folded about a dome of quartz diorite to tonalite gneiss, surrounded by migmatitic syenogranite gneiss, with considerable tectonic disruption and pegmatite injection along the intrusive/supracrustal contact (Figure 034.1). Immediately west of the RLMZ, in the western domain, are several discontinuous patches of muscovite-bearing meta-arenites and muscovite-biotite-sillimanite schists which may be correlative with the Flinton Group (*see* Western Domain below) (Figure 034.1). These rocks are absent from the eastern domain and the RLMZ.

EASTERN DOMAIN

The eastern domain consists of a package of mafic metavolcanic and carbonate rocks intruded by the Lavant Gabbro Complex (Pauk 1984). The metavolcanics are best exposed in the area south of Raycroft Lake and south of Darling Lake (areas II, III, Figure 034.2) and consist mainly of green to pale green weathering, massive, but commonly fractured, aphanitic rocks which are cut by carbonate veins. Locally pillow structures are preserved in these rocks, as are beds of tuff-breccia (Photo 034.1), lapilli-tuff, and thinly to thickly bedded metatuffs. The latter, at amphibolite facies, locally possess "feather amphibolite" textures. Thickness of the volcanic sequence is over 300 m.

The metavolcanic succession is overlain by roughly 100 to 300 m of fine-grained, thinly bedded, silty to sandy clastic metasediments, black shales, felsic tuffs, and cherty beds of mainly volcanic provenance, which are locally pyritiferous and grade into sulphide facies ironstones. These metasedimentary and possibly exhalative rocks are overlain by calcitic and dolomitic marbles which show considerable textural variation. South of Raycroft Lake, dolomitic marble containing algal-laminite stromatolites predominate, whereas south of Darling Lake, thinly bedded, graded, calcite turbidites (Photo 034.2) are present. In the vicinity of Murray Lake, massive dolomite and calcite marbles are present, with calcite marbles being most common in the southeastern corner of the map area. In general, marbles in the eastern domain are relatively clean and free of impurities, although a variety of calcitic marble with quartz-tremolite segregations and pods is common in the southeastern part of the map area.

The supracrustal succession is intruded by fine- to coarse-grained gabbro, diorite, tonalite, and granodiorite of the Lavant Gabbro Complex (Pauk 1984). The Lavant Gabbro Complex consists of two main magmatic suites: a slightly older, and more voluminous, mafic suite dominated by medium-grained gabbro, which locally shows the presence of igneous layering and several compositionally cross-cutting gabbroic and dioritic phases; and a slightly younger tonalite suite which consists of tonalitic and granodioritic rocks which have forcibly intruded the gabbro and diorite phases to form intrusion breccias and small intrusive bodies. The tonalite suite rocks occur mainly in the upper (roof) part of the gabbro and the overlying supracrustal rocks, particularly the marbles. The tonalite suite rocks are intimately associated with the mafic phases of the body, and, as suggested by Pauk (1984), are probably late-stage differentiates of the original magma body.

The Lavant Gabbro Complex does not have an extensive contact aureole with the country rocks, although locally, such as at Marble Bluff, it has serpentinized the surrounding marbles. The Lavant Gabbro Complex has complex contact relationships with the country rocks (Figure 034.1), and includes roof pendants and slivers of all the country rocks, particularly in the southern part of the area (area IV, Figure 034.2).

The eastern domain is divided into several crustal blocks, as shown in Figure 034.2, by late Paleozoic Faults. These faults expose various levels through the Lavant Gabbro Complex and the supracrustal sequence. Block I (Figure 034.2) is the highest level stratigraphically, consisting mainly of marble cut by a few tonalite intrusions. Blocks II and III

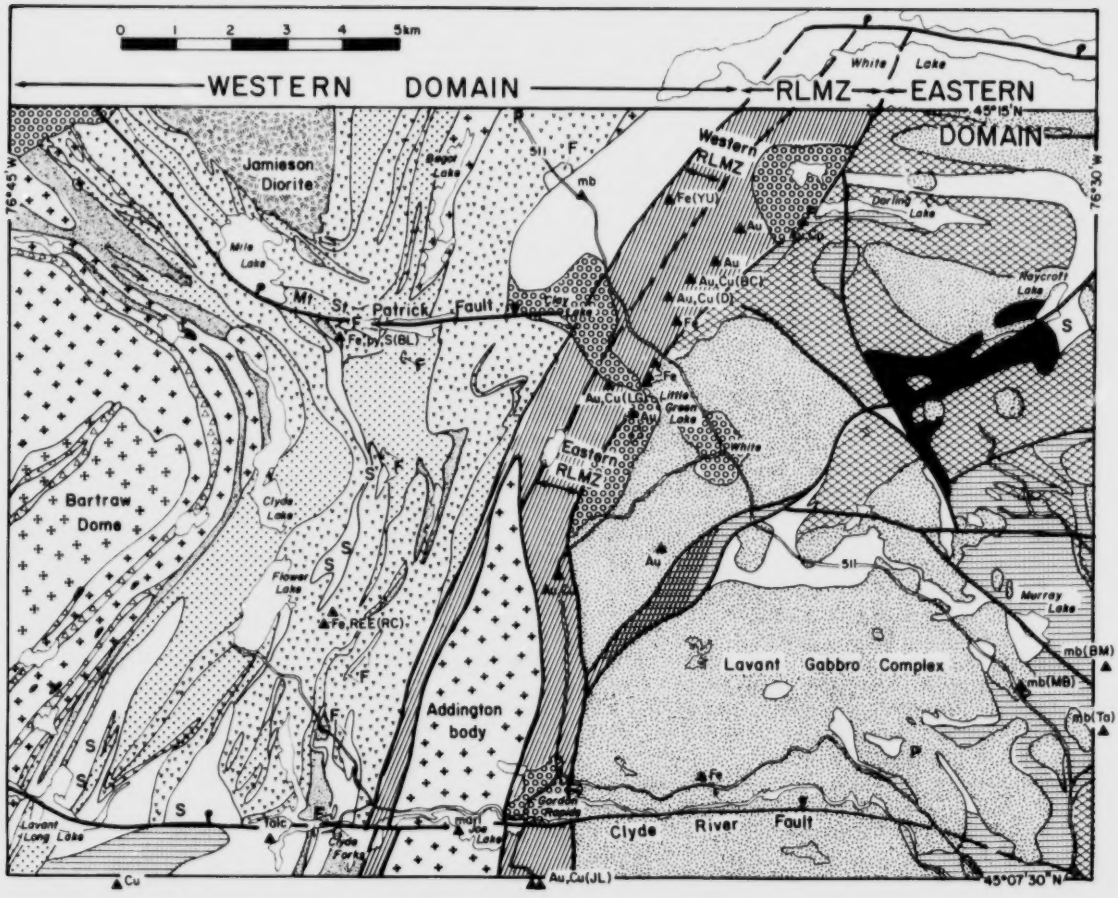


Figure 034.1. *General geology of the Darling area, with major mineral occurrences and deposits, stromatolite localities, and distribution of possible Flinton Group lithologies.*

expose the upper and lower part of the volcanic succession respectively. Block IV exposes the roof of the Lavant Gabbro Complex, and best exposes the contact relationships with the country rocks. The tonalite phase of the Lavant Gabbro Complex is best exposed in this block. Block V is the deepest level stratigraphically, and consists of relatively homogeneous gabbro. Metamorphic grade increases to the south and east as shown in Figure 034.2, with middle to upper greenschist facies rocks being exposed in Blocks V and III, and lower amphibolite facies rocks being exposed in Blocks I, II, and IV.

Cataclasis in all rocks in the eastern domain increases toward the RLMZ. Some fine-grained, sheared and chloritized rocks along the eastern edge of the RLMZ have been mapped in the past as a central volcanic-sedimentary sequence and have been termed the Joe Lake Volcanics (Pauk 1984; Carter 1981; Sangster 1970). In most instances, it is not possible to tell the protolith of these fine-grained rocks which are carbonate-veined, chloritized, protomylonites interlayered with ferroan-dolomite units that are extensively mylonitized (Photo 034.3). It is likely that these rocks represent both mylonitized gabbro and metavolcanics. However, since the protolith of these rocks cannot determined, it is recommended that the term Joe Lake Volcanics be abandoned.

It should be noted that, although carbonate alteration and veining is best developed near and within the RLMZ, such veining and alteration does occur throughout the Lavant Gabbro Complex and the metavolcanic sequence, up to 15 km east of the RLMZ. East of the RLMZ, carbonate alteration is more commonly manifested as a dissemination of brown-weathering carbonate as opposed to extensive veining. Some of this carbonate may not in fact be an alteration effect, but may represent carbonate incorporated in the metavolcanics during eruption, particularly in the case of the metatuffs.

A few general statements can be made about the geological history and paleogeography of the eastern domain. The area was one of active volcanism, of probable Surtseyian type, consisting of the eruption of pillow lava, massive flows, tuffs, and the development of cinder and tuff cones of mainly basaltic composition. In part, these eruptions took place in an active carbonate basin. Locally exhalative activity and wave erosion formed the fine-grained clastic

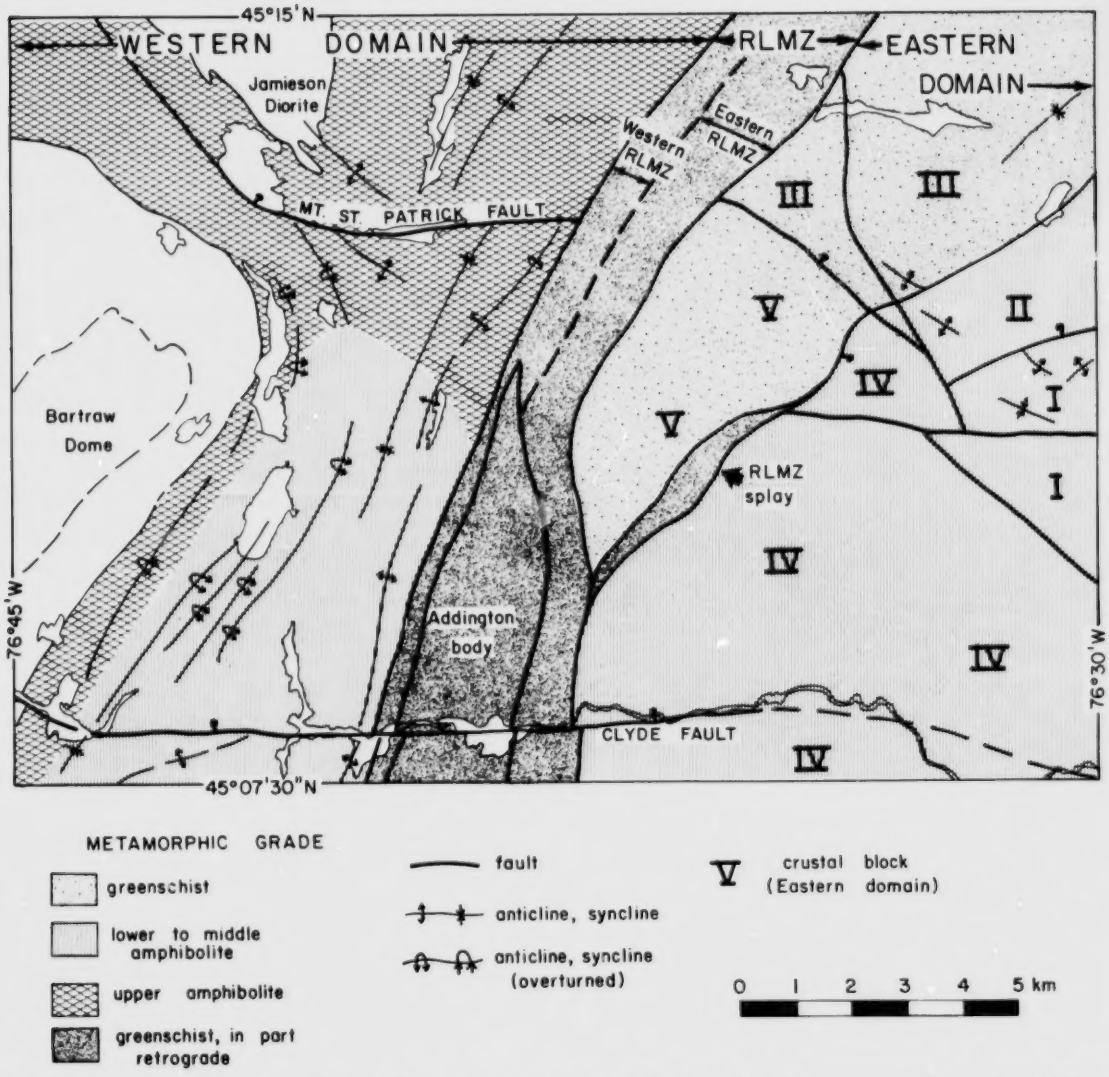


Figure 034.2. *Major structural elements, crustal blocks, and distribution of metamorphic grade within the Darling area.*

sediments and sulphide-facies ironstones. As volcanic activity waned, carbonate deposition increased and buried the volcanic pile. Shallow areas saw deposition of dolomite marbles and algal-mat stromatolites, followed by the deposition of calcite marbles. Deeper areas accumulated thinly bedded calcite turidites. The supracrustal sequence was then intruded by gabbros of the Lavant Gabbro Complex shortly after volcanism ceased, some phases of which may have been feeders to the volcanic succession. Local hydrothermal alteration and carbonate veining occurred in the volcanic rocks near the gabbro. Tonalites were intruded after the gabbro cooled and differentiated. Deformation during the Elzevirian and Ottawan Orogenies led to the present configuration.

WESTERN DOMAIN

The western domain consists of a package of amphibolite and quartzofeldspathic gneisses which are interpreted to be a sequence of mafic, intermediate, and felsic metavolcanics; metasediments, in part derived from a volcanic source; and marbles: all of these units are intruded by several small granite and dioritic intrusions. Rocks of the western domain are more intensely deformed and metamorphosed than rocks of the eastern domain. Deformation has destroyed most original textures in the amphibolites and the quartzofeldspathic gneisses, although locally pyroclastic textures are preserved in both units. In addition, the massive character, grain-size, and homogeneity of the quartzofeldspathic gneisses suggest that they may in part represent pyroclastic flow

PRECAMBRIAN (034)

Quaternary cover

P Paleozoic rocks, regoliths

mylonite (Robertson Lake Mylonite Zone (RLMZ))

EASTERN DOMAIN

gabbro, diorite, tonalite

calcite marble

dolomite marble

pyritiferous metasediments

mafic metavolcanics

WESTERN DOMAIN

muscovitic metasediments (Flinton Gp.)

diorite

granite gneiss

tonalite gneiss

anorthosite

marble breccia

calcite marble

dolomite marble

siliceous clastic metasediments, in part volcanic-derived

intermediate to felsic metavolcanics

amphibolite (mafic metavolcanics)

ABBREVIATIONS

Au – gold
Cu – copper
Fe – iron
mb – marble
py – pyrite
REE – rare-earth elements
S – sulphur

BC Bradford's Creek
BL Blithfield pyrite mine
BM Blue marble
D Darling
JL Joe Lake
LG Little Green Lake
MB Marble Bluff
RC Radenhurst-Caldwell
TA Tatlock
YU Yuill Iron mine

fault, bar on downthrown side

S Stromatolites

mineral occurence, former mine, quarry

LEGEND: *Accompanies Figures 034.1 and 034.2.*

and subaqueous pyroclastic flow deposits. Locally, these rocks grade into arenaceous and biotite-hornblende-quartz-plagioclase gneisses which probably represent sedimentary units derived from the reworking of intermediate to felsic volcanic rocks.

In the western domain, calcitic marbles are predominant mainly in the area south of Flower Lake. Dolomitic marbles dominate further north, particularly where the marbles are associated with mafic and felsic volcanic rocks. Algal-laminite stromatolites (Photo 034.4) are common in the dolomitic marbles associated with the amphibolites, as shown in Figure 034.1, which identifies all known stromatolite localities in the area.

Complex folding in the western domain, which is tight to isoclinal, makes it difficult to unravel the original stratigraphic sequence present in the western domain. In a general sense, the sequence would appear to be mafic volcanic rocks (amphibolite), dolomitic and stromatolitic marbles, calcitic and dolomitic marbles, and intermediate to felsic volcanic rocks, and additional carbonate deposition. Furthermore, there are some major facies changes from north to south and east to west in the western domain. The eastern part of the domain up, to 1 to 2 km west of the RLMZ, is dominated by amphibolite with dolomitic interbeds. To the north, felsic volcanic rocks interfinger with the amphibolites.

The western part of the domain consists of all main rock types, but particularly the carbonate and felsic volcanic rocks. In the south, east of Lavant Long Lake, the supracrustal sequence is dominated by dolomitic and calcitic marbles with thin interbedded layers of amphibolite, quartzofeldspathic gneiss, metawacke and meta-arenite. West of Flower Lake, quartzofeldspathic gneiss interfingers with the marbles, and forms a large body on both sides of Clyde Lake. Further north, the quartzofeldspathic gneisses grade into, and interfinger with, a sequence of para-amphibolite and biotite-hornblende-quartz-plagioclase gneisses, the latter representing volcanic-derived sedimentary rocks. Metamorphic grade also increases from south to north in the western domain, complicating protolith recognition in the northern part of the area.

The west-central part of the domain is underlain by a domal structure (Figure 034.1) cored by quartz diorite to tonalite gneiss, and mantled by a thick unit

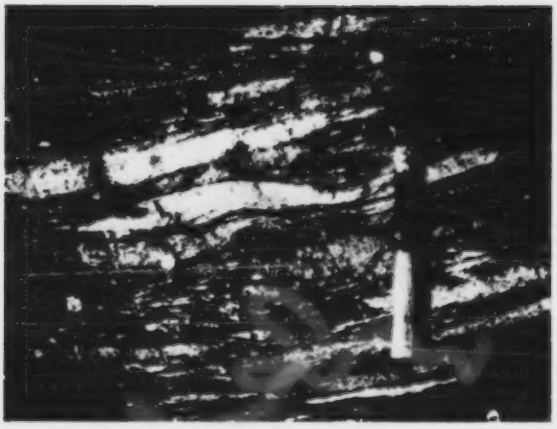


Photo 034.1. *Tuff-breccia consisting of mafic to intermediate composition volcanic fragments in an ash matrix. Block II, 2 km southeast of Raycroft Lake, lower amphibolite facies (UTM 18T, E382050,*

of migmatitic syenogranite gneiss, which engulfs pods of anorthosite and gabbroic anorthosites, amphibolite, para-amphibolite, and calcitic marble breccia. It is unclear if the supracrustal/gneiss contact in this area is intrusive, unconformable, or tectonic.

The supracrustal sequence in the western domain, despite greater deformation and metamorphism, is clearly different from that in the eastern domain. In the western domain, the volcanic sequence consists of roughly equal amounts of mafic, intermediate, and felsic rocks, which interfinger with the carbonate rocks. It appears that the felsic volcanic rocks south of Flower Lake were erupted during active carbonate deposition. The volcanic rocks themselves are distal from the main volcanic edifices as indicated by the lack of coarse pyroclastic units and obvious flow rocks.

About 1 km west of the RLMZ, a number of distinctive, clastic metasediments occurs as a series of discontinuous bands (Figure 034.1), consisting of muscovite-rich, biotite-sillimanite schists and hematite-stained, muscovite-rich meta-arenites and metaquartzarenites. Similar rocks to the south and at Clyde Forks have been correlated with the Bishop Corners Formation of the Flinton Group (Pauk 1984; Rivers 1976). These muscovite-rich rocks in the map area have undergone the same degree of metamorphism and deformation as the surrounding rocks. No evidence for an unconformable relationship with the Grenville Supergroup could be found in the area, and other than a slightly aluminous bulk-rock composition, there is no *a priori* reason to consider these rocks as part of the Flinton Group. It is conceivable that other Flinton Group rocks may be present in the area, for example dolomitic marbles, but lacking any other distinctive lithological traits, they cannot be distinguished from the Grenville Supergroup within the map area.

ROBERTSON LAKE MYLONITE ZONE (RLMZ)

The Robertson Lake Mylonite Zone (RLMZ) was first named by Smith (1958) as the Robertson Lake Shear Zone which extended from Lavant Lake to Joe Lake. Smith (1958) did not put precise limits on the width or extent of the zone, but subsequent mapping has traced the zone 20 km to the north to White Lake (Carter 1981; Jackson 1980), and 50 km to the south (Wolff 1982; Pauk 1984) (Figure 034.3).

Carter (1981), Jackson (1980), and Pauk (1984) all recognized that the zone contains mylonitic rocks, and Carter (1981) and Jackson (1980) defined the zone as a band of ultramylonites that occur mainly east of the Addington Pluton, although both report a thin mylonite zone on the western side of the Addington Pluton. As defined here, the RLMZ includes the mylonite zones on both sides of the Addington Pluton as shown in Figure 034.1, and includes both ultramylonite and protomylonites. The Addington Pluton in the area is a large block of material caught up within the RLMZ. The RLMZ dips to the south-southeast at about 50° to 40° along its western margin and from 20° to 15° along its eastern margin.

The mylonites in the RLMZ vary according to the nature of the adjacent country rocks, an effect most noticeable along the western margin of the RLMZ mainly because of the greater lithologic variation that occurs from north to south along the western margin. In the southern part of the area, where the Addington Pluton is preserved as a sliver within the mylonite zone, the western RLMZ consists mainly of felsic ultramylonite, whereas the eastern RLMZ consists of ultra- and protomylonites derived from mafic metavolcanics, gabbro, and marble. North of the Addington body, the two-fold character of the RLMZ persists, with the eastern zone consisting of chloritized ultra- and protomylonites derived from metagabbro and dolomitic marbles (Photo 034.4). There, the western RLMZ consists of mylonite derived from amphibolite and metadiorites, both of which are less chloritized than rocks to the east. Further north, near the northern boundary of the map area, the western RLMZ contains abundant bands of mylonitic dolomite marble, reflecting a thick band of dolomite west of the RLMZ.

Au-Sb-Cu deposits in the area previously described in detail by Carter *et al.* (1980) and Carter (1981) (Figure 034.1) and new deposits outlined by Gleeson-Rampton Explorations Limited (AFRO) (Figure 034.1) are hosted generally in ferroan dolomite horizons, and all occur with the eastern part of the RLMZ, the zone derived from the eastern domain lithologic sequence. Although Carter (1981) is probably correct in stating that these deposits were initially syngenetic, alteration and carbonatization associated with development of the RLMZ has probably served to concentrate mineralization within the RLMZ.

The RLMZ is a major tectonic feature that extends over 90 km from the Precambrian-Paleozoic boundary north to White Lake (Figure 034.3). It separates rocks that are lithologically distinct and that have had different deformational and metamorphic histories, and juxtaposes rocks of vastly different metamorphic grade. The RLMZ is probably a low-angle thrust fault along which rocks to the east have

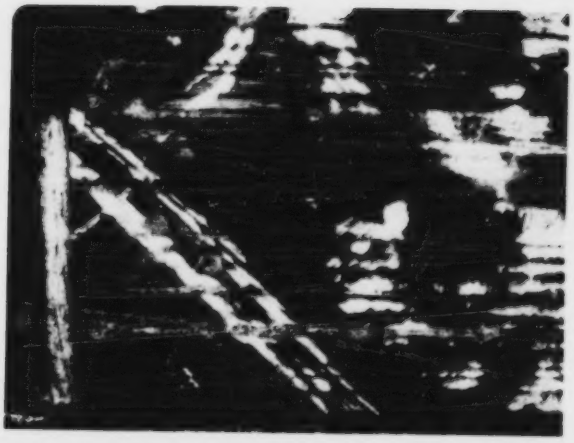


Photo 034.2. *Graded bedding in calcite turbidities, Block III, 2 km south of Darling Lake in area of middle greenschist facies (UTM 18T, E377230, N5008800).*

been thrust westward over higher grade rocks. The RLMZ probably developed during the Ottawan Orogeny, but it may have had some later movement, as the Mt. St. Patrick Fault (late Paleozoic) appears to be truncated by it, although the Clyde River Fault seems to offset it (Figure 034.1). In fact, the preservation of low metamorphic grade rocks along the fault may be related to vertical movement along the RLMZ in the late Proterozoic-early Paleozoic.

ECONOMIC GEOLOGY

GOLD-COPPER-ANTIMONY DEPOSITS

Carter (1981), Carter *et al.* (1980), and Pauk (1984) describe these deposits both within the map area and in the Lavant area to the south. Extensive descriptions, including assay values and grade and tonnage estimates, are provided in Carter *et al.* (1980). The deposits described by Carter *et al.* (1980) are all located in the eastern part of the RLMZ and are hosted in ferroan dolomite. Mineralization consists of gold in association with tetrahedrite and pyrite, with azurite and malachite staining commonly associated with the tetrahedrite. Gleeson-Rampton Explorations Limited have also located several other occurrences within the RLMZ (AFRO); these are shown in Figure 034.1. The most noteworthy of these other occurrences is located on the southwestern shore of Darling Lake (Figure 034.1), and is hosted in weathered, hematitized carbonate; it is possible that gold in this showing has been enriched due to weathering. Rampton *et al.* (1986) noted that till geochemistry is a useful exploration tool within the RLMZ and the eastern domain. Two assay samples collected by field party personnel from this showing gave values of 4850 and 875 ppm Cu, and 70 and 140 ppb Au.

While the eastern RLMZ, as a whole, remains the most favourable target zone for gold exploration within this target area, intersections of the RLMZ with other faults and splays off of the main zone may make most worthwhile exploration targets. The Bradford's Creek Deposit (lot 23, concession V, Darling Township) is in an area undergoing logging, and is difficult to find because of deadfall and secondary vegetation growth.

OTHER PRECIOUS AND BASE METAL PROSPECTS

A sample from a weathering crust on Highway 511, 500 m south of the northern sheet boundary (UTM 18, E371925, N5011650) assayed 15 ppb Au and 170 ppm Cu. Gleeson-Rampton Explorations Limited regarded 10 ppb Au as anomalous (AFRO).

No previous exploration or assessment work has been filed on the area of pyritiferous metasediments southwest of Raycroft Lake (Figure 034.1), although the area has been staked at various times. Gleeson-Rampton Explorations Limited reported a gold anomaly in soil over the western contact of this zone along the Indian River (AFRO). Grab samples from this unit collected by field party personnel showed no systematic or consistent metal values, although various samples were enriched in gold (15 to 30 ppb), copper (150 to 300 ppm), and zinc (400 to 500 ppm) in comparison to barren samples from the same unit. This zone may warrant additional exploration.

Carter *et al.* (1980) describe in detail the other base metal occurrences in the map area, most notably the Blithfield Pyrite Deposit (lots 1, 2, concession I, Blithfield Township). Assay samples collected from this deposit by field party personnel showed no metal or gold enrichment. Since the writing of the report by Carter *et al.* (1980), the ore dump has been bulldozed and the shafts filled, so that most features described by Carter *et al.* (1980) are no longer visible.

Exploration for copper was conducted in the Bagot Lake area in 1977 by Canadian Occidental Petroleum Limited in an area underlain by amphibolite and quartzofeldspathic gneisses (mafic and felsic metavolcanics) of the western domain (AFRO). Dolomitic marbles in the area, particularly those containing stromatolites, may be worthwhile targets for zinc mineralization.

The Lavant Gabbro Complex has been poorly studied in the past, and no geochemical data exists on this complex. It is, however, a differentiated igneous intrusion, and is locally layered, showing a considerable compositional range from ultramafic phases to gabbroic anorthosite. It may be a worthwhile target for platinum exploration, both within the map area and the Lavant area to the south.

IRON AND RARE EARTH ELEMENT MINERALIZATION

Carter *et al.* (1980) described in detail several small massive magnetite deposits within the Darling area. Deposits in the eastern domain (Darling Deposits; lots 20 and 22, concession IV and V; lots 21, 22, concession III, Darling Township; Yuill Deposit, lot 25, concession V, Darling Township; Lavant Deposit, lot 11, concession I, Lavant Township; several aeromagnetic anomalies reported by Gleeson-Rampton Explorations Limited (AFRO)) occur within the margin of, and as contact metasomatic deposits associated with the Lavant Gabbro Complex. Deposits in the western do-

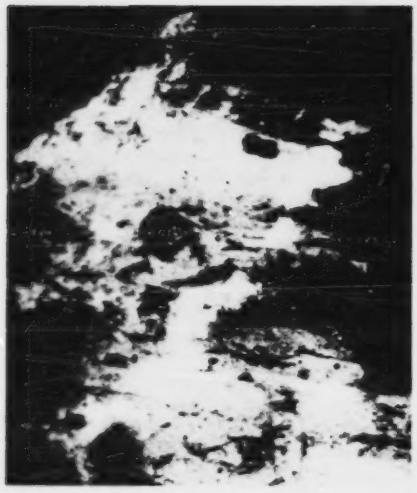


Photo 034.3. *Marble mylonite along the eastern margin of the RLMZ previously mapped as a dolomite unit in the Joe Lake Volcanics. Note the mylonitic layering in the marble wrapping arounded angular quartz fragments (UTM 18T, E374150,N5002350).*

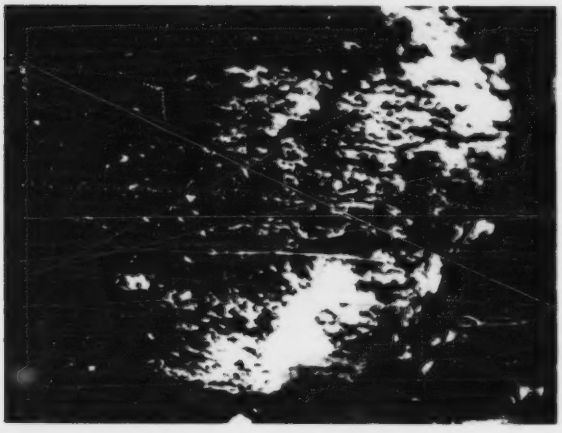


Photo 034.4. *Algal-laminite stromatolite (Eozoon canadense huntingdon) in dolomite marbles, 1 km east of Flower Lake, western domain (UTM 18T, E368250,*

main are found as massive magnetite within the amphibolite succession, and may be related in origin to the metavolcanics. The largest of these is the Radenhurst-Caldwell Deposit (lot 22, concession III, Lavant Township) described in detail by Carter *et al.* (1980). An assay sample from this deposit collected by field party personnel assayed 1200 ppm La; 1450 ppm Ce; and 385 ppm Nd. In this respect it is similar to the Victoria Iron Mine in the Minden area which is also LREE-enriched (Easton 1987). Additional work on this deposit for rare earth element mineralization is probably warranted.

MARBLE

The presence of an operating quarry and a past producer adjacent to the map area indicates that the area may have considerable potential for marble production in the future. Exploration for clean calcite marbles of the type produced currently at Tatlock should focus on the southeastern corner of the map area, particularly east and north of Murray Lake in Block I (Figure 034.2). Calcitic marbles in Block IV (Figure 034.2) of the eastern domain may also be favourable. Large areas of clean dolomitic marbles exist west of Murray Lake, and along the White Lake road where it joins with Highway 511. Unusual varieties of marble occur at Marble Bluff (UTM 18, E380750, N5001200) where a patterned, green serpentine marble is present in contact with gabbro, and south of Raycroft Lake (UTM 18, E381825, N5007760), where a 20 to 30 m band of clean, pink marble extends along a strike length of 200 to 300 m. In the western domain, the best exploration area for marble is east of Lavant Long Lake where a variety of marble types is exposed along a forest access road. A band of calcite marble is present along the contact of the supracrustal sequence and the migmatitic syenogranite gneisses to the west, and contains 0.5 to 1% graphite and 1% coarse phlogopite. It is the most consistently graphitic marble unit in the area.

INDUSTRIAL MINERALS

Marl has been reported on the western shore of Joe Lake (Storey and Vos 1981b) and may be present in the area of Clay and Little Green Lakes. Quartz-tremolite horizons are present within many of the dolomite marbles although no massive deposits were located by field party personnel. No surface graphite prospects were located; however, the RLMZ and the faults in the eastern domain (Figure 034.2) may be potential exploration targets for graphite. Some of the Flinton Group correlatives west of the RLMZ are rich in muscovite, and this discontinuous band of rocks, and similar rocks to the south in the Lavant area, may have potential as muscovite-producers.

Sand and gravel occur extensively in the map area, and some deposits have already been exploited locally. They occur mainly along the RLMZ and Highway 511, and include the delta complex north of Joe Lake near Gordon Rapids, the kame complex south of Little Green Lake, and an extensive sand and gravel plain north of White.

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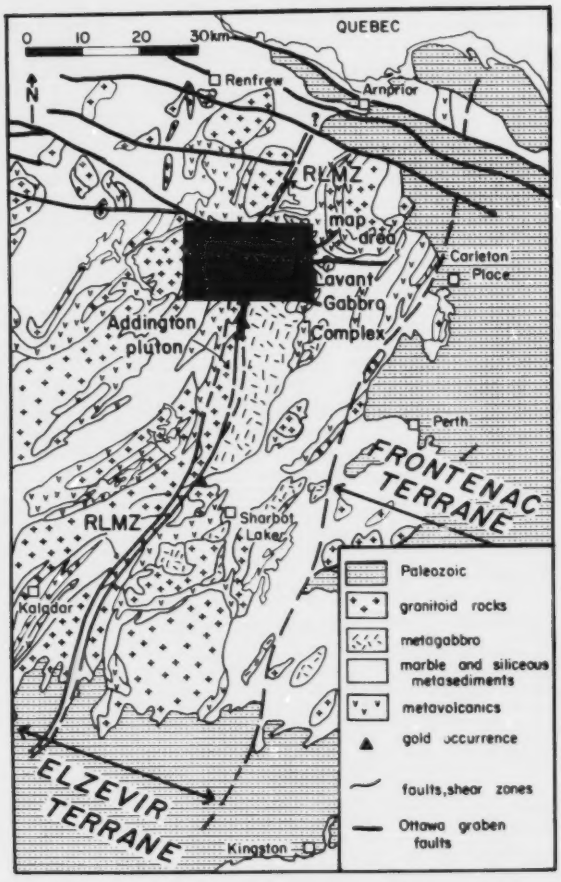

Figure 034.3. *Regional extent of the Robertson Lake Mylonite Zone.*

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035. Sr–Y–Zr–Nb Enriched Rocks from the Minden Area, Grenville Structural Province

R.M. Easton

Geologist, Precambrian Geology Section, Ontario Geological Survey.

INTRODUCTION

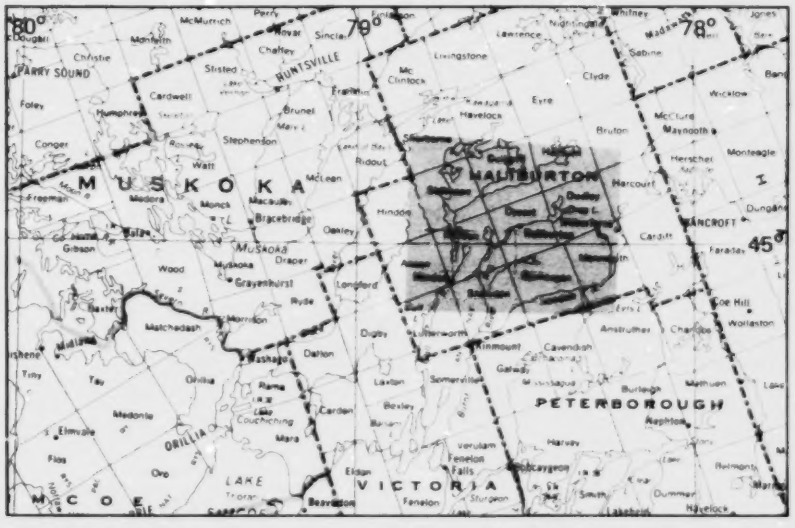
The Minden area is located in northwestern Haliburton County, and lies 140 km northeast of the City of Toronto. It is accessible by Highway 35 from Peterborough to the south, and by Highway 121 and 503 from Bancroft to the east. Detailed mapping in the Minden area at 1:15 840 scale was conducted by the Ontario Geological Survey from 1983 to 1986 (Easton 1986, 1987; Easton and Van Kranendonk 1987; Easton *et al.* 1987). During the course of these earlier investigations, a zone of rusty paragneisses, enriched in a variety of trace elements, most notably Ba, Sr, Y, Zr, and Nb, was located about 2 km east of Minden and which could be traced for about 5 km along strike (Easton and Van Kranendonk 1987) (Figure 035.1). About a week during the 1987 field season was spent conducting additional mapping and geochemical sampling of this unit and associated rocks, to better define its regional extent and mineral potential, and to further document the geologic setting of these anomalous rocks.

GENERAL GEOLOGY

The Minden area straddles the boundary between the Central Metasedimentary Belt and the Central Gneiss Belt of the Grenville Province, with a 2-5 km wide boundary zone of tectonites separating the two major divisions of the Grenville Province in Ontario. Figure 035.1 is a generalized geologic map of the Minden-Haliburton area showing the main tectonic divisions in the area, and the distribution of the rusty paragneiss unit and a variety of lithologically and chemically unusual metasedimentary, metavolcanic, and meta-igneous rocks associated with the rusty paragneiss.

This package of chemically unusual rocks, described in detail below, is located within the Central Metasedimentary Belt, within the Denna Lake Structural Complex (Easton 1986, 1987, in press); a zone composed mainly of marble tectonic breccia, but which also contains large, relatively intact, slivers of meta-igneous rocks. The Denna Lake Structural Complex possess a ghost stratigraphy (Easton 1985), that can generally be matched with the stratigraphic sequence found in less disrupted Grenville Supergroup rocks 20 km southeast of Minden (Easton 1986, in press; Easton and Van Kranendonk 1987).

The package of rocks under study consists of four main rock types which are spatially associated with each other in the Denna Lake Structural Complex (Figure 035.1): (a) a rusty paragneiss unit consisting of rusty-weathering, thinly-layered (probably bedded), quartzofeldspathic schists to gneiss that are commonly intruded by coarse-grained, allanite-bearing syenite veins. It was in these rocks that Sr-Y-Zr-Nb enrichment was first noted (Easton 1985; Easton and Van Kranendonk 1987) (Table 035.1), (b) a marble breccia unit that contains abundant quartzofeldspathic gneiss, amphibolite, and calc-silicate blocks, found only in close spatial association with the rusty paragneiss or amphibolite rocks in the area (Figure 035.1). Allanite-bearing syenite veins also occur in these rocks. In contrast to these heterolithic marble breccias, neighbouring marble breccia units in the Denna Lake Structural Complex generally have a restricted variety of clasts. Samples from the matrix of this marble breccia unit collected in 1987 also contain high Sr-Y-Zr contents compared to other mar-



LOCATION MAP Scale ; 1: 1 548 000 or 1 inch to 25 miles

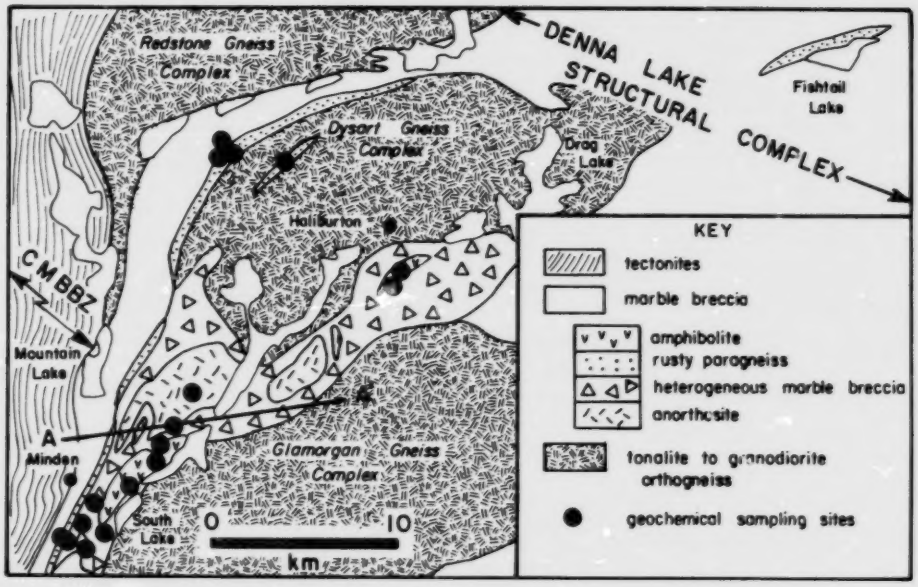


Figure 035.1. *Generalized geology of the Minden-Haliburton area, showing distribution of rusty paragneiss, heterolithic marble breccia, amphibolite and anorthositic units. Line A-A' shows approximate line of cross-section illustrated in Figure 035.2b. Abbreviation: CMBBZ - Central Metasedimentary Belt Boundary Zone.*

ble breccia and marble units in the area (Table 035.2), (c) a unit of fine- to medium-grained amphibolite, generally thinly-to medium-layered, possibly representing fine-grained tuffs or reworked tuffs. The amphibolites are associated with a diopside-plagioclase rock, commonly pegmatitic, present as pods and layers with the amphibolite, and as clasts within the marble breccia. The amphibolites are more alkaline than other amphibolites in the area (Easton, in press), and some amphibolite layers, and the diopside-plagioclase rock also contain abnormal Sr-Y-Zr-Nb contents (Table 035.1); and (d) the three lithologies above all occur adjacent to the Allsaw Anorthosite and several smaller anorthosite bodies which are disrupted slices from a once more extensive gabbroic anorthosite-anorthosite body. As noted previously (Easton 1986, in press), this body is alkaline in its chemistry, showing very low abundances of P_2O_5, Fe, Ti, V, Y, and Zr, and which has rare-earth element patterns identical to monzodioritic and plagioclase-rich bodies from the Gooderham Syenite Belt to the southeast. It is chemically distinct from the subalkaline Central Gneiss Belt anorthosites (Easton, in press; Easton and Van Kranendonk 1987) and probably is a disrupted equivalent of a Gooderham Syenite Belt body caught up in the Denna Lake Structural Complex.

DISCUSSION AND INTERPRETATION

The band of rusty-weathering paragneisses can be traced discontinuously north-northeast of Minden, where along strike (Figure 87.35.1) it corresponds to a band of garnet-orthoamphibole-bearing gneisses interbedded with sillimanite, cordierite, and biotite-bearing quartzofeldspathic gneisses mapped along the northern margin of the Dysart Gneiss Complex by Culshaw (1986). Garnet-orthoamphibole gneisses farther to the northeast at Fishtail Lake described by Lal and Moorhouse (1969) may also be related to this zone of rusty-weathering gneisses.

In the Minden area, the rusty-weathering paragneisses, and to some extent the heterolithic marble breccia and the amphibolites, are cut by allanite-pyroxene-bearing syenite and quartz-syenite veins. In the case of the rusty-weathering paragneisses, the veins appear to represent anatectic metals derived from the paragneiss (Easton, in press). The bulk chemistry of the paragneiss and the veins corresponds to a phonolite (Table 035.1).

Furthermore, the spatial association between the paragneiss, the amphibolites, the diopside-plagioclase rocks, the heterolithic marble breccia, and the anorthosites does not appear to be strictly tectonic, since rocks of these compositions do not occur elsewhere or randomly in the Denna Lake Structural Complex. This is consistent with the observations to the southwest that the Denna Lake Structural Complex does preserve a ghost stratigraphy (Easton 1985, 1986). The trace element chemistry of all the rock types, and the major element chemistry of the paragneiss, the amphibolites, and the anorthosite are typical of alkaline volcanic rocks of nephelinite/phonolite/silico-carbonatite affinity.

Lal and Moorhouse (1969) and Culshaw (1986) present major element, but no trace element, analyses on the possible northern equivalents of the rusty paragneiss. The data of Culshaw (1986) is similar to that found for the rusty paragneiss in the Minden area, and he also notes the association between the syenite veins and the paragneiss. The data of Lal

TABLE 035.1. REPRESENTATIVE CHEMICAL ANALYSES FROM ROCK UNITS IN THE MINDEN AREA.

	1 Amphibolite	2 Anorthosite	3 Rusty Para-gneiss	4 Rusty Para-gneiss	5 Rusty Para-gneiss	6 Syenite	7 Computed Parent	8 Phonolite (East Africa)
SiO_2	51.8	50.9	54.9	66.7	49.2	62.4	57.2	53.4
TiO_2	0.67	0.09	0.49	0.49	1.35	1.64	0.81	0.85
Al_2O_3	13.90	29.30	16.8	14.00	17.2	15.8	17.4	20.53
Fe_2O_3	2.21	0.04	4.16	NA	4.97	1.80	6.1	4.43
FeO	4.28	0.58	5.01	6.3	4.53	1.19		
MnO	0.13	0.01	0.15	0.19	0.16	0.09	0.10	0.15
MgO	4.86	0.32	3.60	2.35	3.57	0.89	1.9	0.03
CaO	14.20	12.60	6.59	1.11	7.22	3.29	4.5	2.9
Na_2O	3.13	5.22	4.43	5.19	5.68	5.62	5.4	10.15
K_2O	2.01	0.48	1.07	0.50	1.91	5.04	4.4	5.3
P_2O_5	0.07	0.01	0.10	0.14	0.20	0.25	0.10	0.24
H_2O^+	0.61	0.29	0.67	NA	0.98	0.30		
H_2O^-	0.07	0.01	0.07	NA	0.43	0.13		
CO_2	1.17	0.63	0.18	NA	0.32	0.02		
LOI	1.20	0.80	0.4	NA	2.5	0.5		
Total	99.1	100.5	98.6	NA	97.3	98.3		
ppm								
Ba	NA	420	NA		NA	80	NA	
Cu	NA	8	8		250	5	128	
Nb	10	4	5		16	2	20	
Rb	50	0	15		64	145	205	
S	620	1000	468		499	902	700	
V	105	11	NA		NA	6	NA	
Y	34	2	30		95	40	68	
Zn	NA	30	67		240	96	168	
Zr	180	0	111		330	660	495	

NA not analyzed
1) 85RME-0093, Easton in press; 2) 85RME-0381, Easton 1986, in press; 3) 87RME-0400; 4) Culshaw, 1986; 5) 87RME-902A; 6) 87RME-902C; 7) analyses 5 and 6; 8) East African phonolite, Easton, in press.

Analyses from Geoscience Laboratories, Ontario Geological Survey unless stated otherwise. Computed parent is based on 50:50 mixing of syenite and rusty paragneiss from the same outcrop (analyses 5 and 6). Computed parent is roughly equivalent to a phonolite.

and Moorhouse (1969), although equivocal, is consistent with the rocks being originally alkaline in character, but modified by later processes such as weathering or anatexis.

It is proposed here that all of these rocks represent metamorphosed alkaline volcanic and subvolcanic rocks. Major element geochemistry in alkaline rock suites is commonly quite varied over short distances and between individual beds because it is greatly affected by mineral concentration in layers (R. Sage, Geologist, Ontario Geological Survey, Toronto, personal communication, 1987). This would account for some of the extreme variation observed near Fishtail Lake for example. In addition, fenitization commonly occurs in such rock suites, and would further distort major element geochemical signatures.

Figure 035.2 is a sketch which attempts to relate these rock types into a model, a model which also explains their current relationships. The amphibolites and rusty-paragneisses are interpreted to represent metamorphosed alkaline basalt flows and tuffs, phonolite, trachytic, and possible silico-carbonatite pyroclastic rocks respectively. Some of the marble breccias may represent true silico-carbonatite breccias, or tectonic breccias formed by disruption of a sequence of interlayered alkaline basalt, phonolite, and silico-carbonatite tuffs and flows. The Allsaw Anorthosite, and metagabbros and metapyroxenites further north (Culshaw 1986), are possibly subvolcanic alkaline igneous rocks. The diopside-plagioclase rocks may represent meta-ijolites. Weathering after deposition would have also caused further chemical variation in the rocks. During metamorphism and deformation the rocks were metamorphosed to amphibolite grade, locally melted to form syenite veins, and tectonically disrupted. This model is consistent with the chemistry seen in the rocks, explains the association of a group of otherwise unusual rocks, and should assist exploration; however, further work is needed to test the applicability of the model.

ECONOMIC GEOLOGY

Strontium metal is currently only produced in Canada from the Chromasco Division of Timminco Limited plant at Haley, Ontario from imported material (Easton *et al.* 1986). The presence of high strontium values in

TABLE 035.2. PARTIAL CHEMICAL ANALYSES IN PPM OF CARBONATE MATRIX OF HETEROLITHIC MARBLE BRECCIA UNIT, DIOPSIDE-PLAGIOCLASE ROCK, AND PARAGNEISS CONTAINING SMALL LENTICLES (METATUFF?) FROM THE MINDEN AREA.

Sample Number	Y	Sr	Zr	Ba
CARBONATES				
87RME-001	7	715	97	362
87RME-002	9	806	106	284
87RME-012	29	2156	89	328
87RME-407	22	1019	116	436
87RME-901	66	965	107	78
87RME-905	8	487	77	98
87RME-906	9	403	69	93
background (Easton 1987)	<10	100-350	10-20	150-300
Carbonatites (LeBas 1981)	10-130	900-7500	50-300	400-2900
DIOPSIDE-PLAGIOCLASE ROCK				
87RME-405	9	1019	138	153
METATUFF				
87RME-406	22	408	104	384
87RME-400	30	468	111	
background (Easton 1987)	20-30	100-200	100-200	

Analyses from Geoscience Laboratories, Ontario Geological Survey unless stated otherwise.

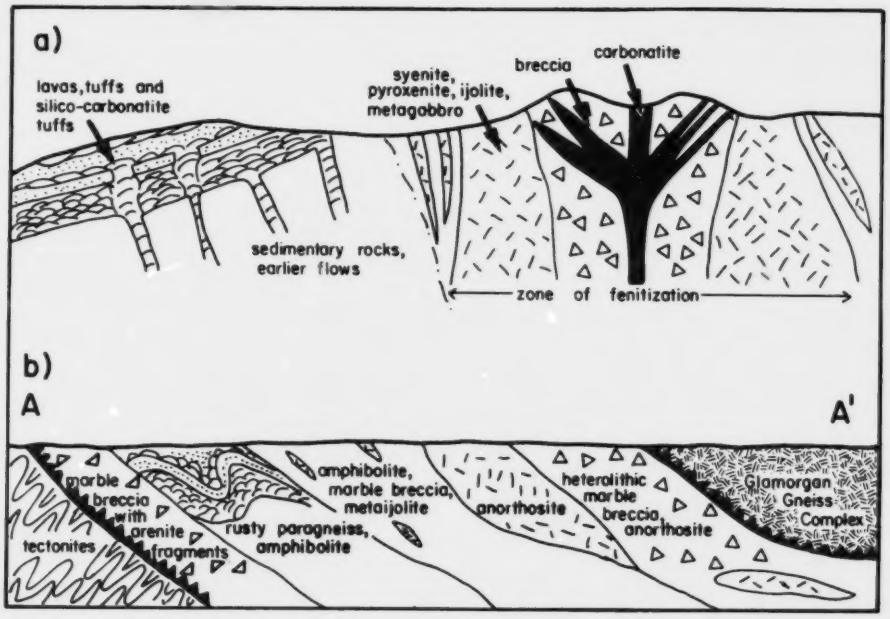


Figure 035.2. *a) Inferred geologic setting of rock units in Minden area during deposition. Figure not to scale. b) Present setting of rock units in the Minden area. Figure not to scale.*

marble units in the Minden area is encouraging from the standpoint of locating a domestic source, and further exploration in the area should concentrate on finding a relatively clean, preferably unbrecciated, strontium-rich zone which could be exploited. Exploration should not only focus on the Minden area, because if the rocks in the Minden area do represent a metamorphosed alkaline volcanic and subvolcanic complex; then less disrupted equivalents of these rocks should be present in the Gooderham and Tory Hill syenite belts west of Bancroft north and south of Highway 503. Furthermore, rather than simply sampling for strontium in the marbles, the lithologic association of rusty paragneisses, amphibolites, and plagioclase-rich meta-igneous rocks associated with marbles and marble breccias should provide a useful tool for targeting areas for exploration.

In addition to strontium, other metals such as Zr, Y, and Nb may be locally enriched in these rocks, and may be present in economic concentrations. Again, both the Minden area and the Gooderham and Tory Hill Syenite Belts are likely exploration targets.

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036. Ferrie River Area, Parry Sound District

G.D. McRoberts and M.L. Tremblay

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

The Ferrie River area is located approximately 50 km northeast of the Town of Parry Sound and includes parts of East Mills, Ferrie, Wilson, Lount, Pringle and McKenzie Townships. The map area is bounded by Latitudes 45°45'N and 45°52'30"N and by Longitudes 79°45'W and 80°00'W. Field investigations in 1987 represent the northward extension of geological mapping at a scale of 1:15 840 that had begun in 1986.

Access to the northwestern, northeastern, and southeastern parts of the map area is by various service roads south from Highway 522 and by canoe. Access into the central and southwestern parts of the map area is by service road north from Highway 520 and by all-terrain-vehicle trails, canoe, and by float-equipped aircraft.

MINERAL EXPLORATION

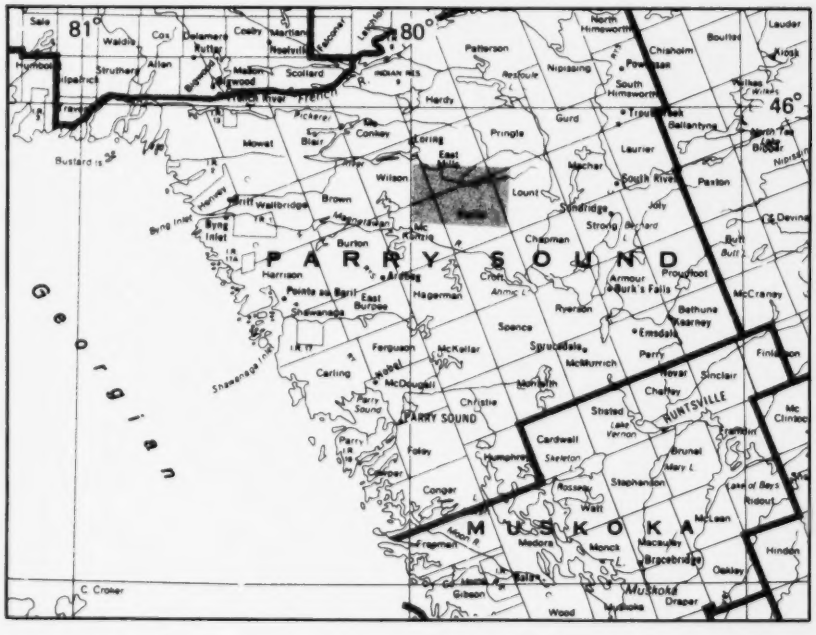
Mineral exploration in the Parry Sound and surrounding area dates back to the late nineteenth century; however, there is no record of exploration within the map area at the Assessment Files Research Office, Ontario Geological Survey, Toronto (AFRO) or at the Resident Geologist's Office, Dorset, Ontario. However, Satterly (1956) describes several mineral occurrences which have been the focus of exploration in Lount Township east of the map area and include magnetite, copper, feldspar, garnet, graphite, mica, molybdenum, the rare earth elements, and radioactive minerals.

Recent exploration work in Ferrie Township 2 km southeast of the map area consisted of 13 drillholes in marble by E.T. Jones.

GENERAL GEOLOGY

The Ferrie River area is underlain by Precambrian rocks of Middle Proterozoic age which form part of the Central Gneiss Belt of the Grenville Province. The map area adjoins the Whitestone Lake area mapped by Bright (1986) to the south. Lount Township was mapped by Satterly (1956).

Davidson and Morgan (1981), Davidson *et al.* (1982), and Culshaw *et al.* (1983) subdivided the Central Gneiss Belt into several domains and subdomains (Figure 036.1) based on lithological, metamorphic, and structural criteria. The westernmost 20% of the map area lies within the Britt Domain whereas the eastern half is within the Parry Sound Domain (Figure 036.2). A ductile shear zone, referred to as the Parry Sound Shear Zone by Davidson



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

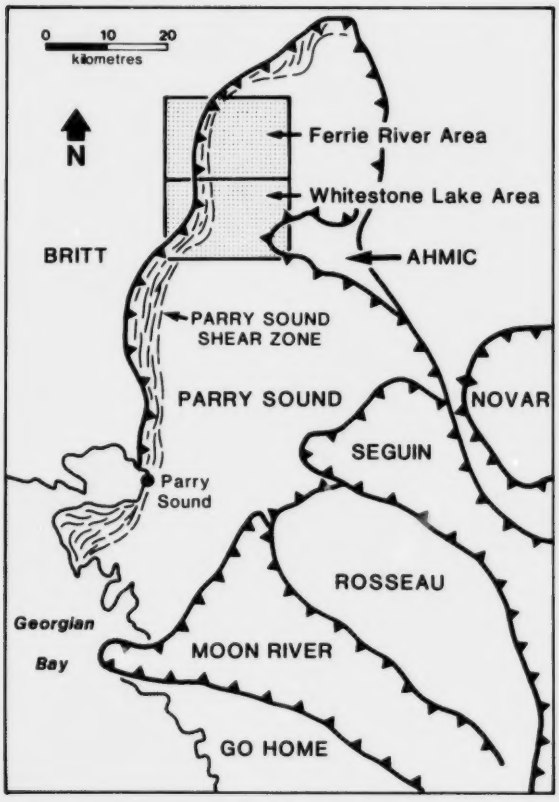


Figure 036.1. *Domains and subdomains in the Parry Sound Region of the Central Gneiss Belt (after Davidson, 1984a) showing the location of the Ferrie River and Whitestone map areas.*

(1984a) separates the two domains in the map area (Figure 036.2).

PARRY SOUND DOMAIN

The Parry Sound Domain is characterized by interlayered north to northeast-trending, tectonically modified zones of rock of varied width, length and composition. Several relatively wide lenses or belts (200 m to 1 km), which consist mainly of one or more of metadiorite, metagabbro or quartzofeldspathic and feldspathic gneisses, extend through most of the map area (Figure 036.2). Numerous, narrow, discontinuous zones consisting of one or more of dioritic, anorthositic, gabbroic and quartzofeldspathic rocks or marble tectonic breccia occur within the wider lenses or belts or along their boundaries. Many of the narrow zones are discontinuous along strike. Zones of marble breccia and quartzofeldspathic gneisses are commonly interlayered. The anorthositic Raganooter Lake body occurs in the western side of the Parry Sound Domain (Figure 036.2). It contains relict igneous textures and structures and is non-foliated to strongly foliated. All contacts, where observed, are tectonically modified.

Within the Parry Sound Domain, hornblende + pyroxene metadiorite and metaquartzdiorite are generally weakly foliated, fine to medium grained and massive-looking. Hornblende + pyroxene + quartz + feldspar leucosome and compositional layering occur rarely. These rocks are correlated with the McKellar Gneiss south of the map area. An age of intrusion of 1425 ±75 Ma and an age of metamorphism of 1160 Ma have been reported for this gneiss (van Breemen *et al.* 1986).

Metagabbroic rocks are fine to medium grained, generally weakly foliated and consist of hornblende, garnet-hornblende, garnet-hornblende-pyroxene, garnet-pyroxene and pyroxene metagabbro and metaleucogabbro. In contrast to the metadioritic rocks, they are generally garnet-bearing and locally contain a coarse, clotty texture and thin, discontinuous, ultramafic bands. Metagabbroic rocks occur locally as dike-like bodies in metadiorite, quartzofeldspathic gneiss, marble and in anorthositic rock. These are interpreted as dikes and are not necessarily of one age.

Leucocratic, fine- to medium-grained, quartzofeldspathic and feldspathic gneisses are non-foliated to strongly foliated and lineated. Locally developed layering is generally straight, continuous and of constant thickness. Most gneisses are of indeterminate origin but those with sillimanite and mauve-coloured garnet probably are of metasedimentary origin.

Marble tectonic breccia is characterized by 1 to 20% tectonically modified fragments of varied size and composition in a medium- to coarse-grained, calcitic matrix. Thinly-layered dolomitic and calcitic marble occur locally.

A small body of non-foliated, olive brown, fine- to medium-grained norite occurs east of Stanly Lake. Pegmatitic granitoid dikes, locally cataclastic, are relatively rare.

Granulite and amphibolite facies mineral assemblages are common throughout the Parry Sound Domain.

BRITT DOMAIN

The Britt Domain is underlain mainly by interlayered, migmatitic, quartzofeldspathic gneisses of indeterminate origin and migmatitic, granitic to monzonitic orthogneiss. Biotite and hornblende-rich quartzofeldspathic and feldspathic gneisses, mafic gneiss, norite, quartzose gneiss and pegmatitic granitoid veins occur locally.

Orthogneiss occurs along the eastern margin of the Britt Domain through most of the map area. The orthogneisses which are abundant in the northwestern and southwestern parts of the map area are part of a regionally extensive body outlined by Davidson *et al.* (1982). Orthogneisses are fine to medium grained, augen-textured, and weakly to strongly flattened. Xenoliths of quartzofeldspathic gneiss occur locally. Fine- to medium-grained quartzofeldspathic gneiss is massive and layered and comprise up to 15% combined magnetite + epidote + hornblende + biotite, but very leucocratic varieties are common too. Norite is similar to that found in the Parry Sound Domain.

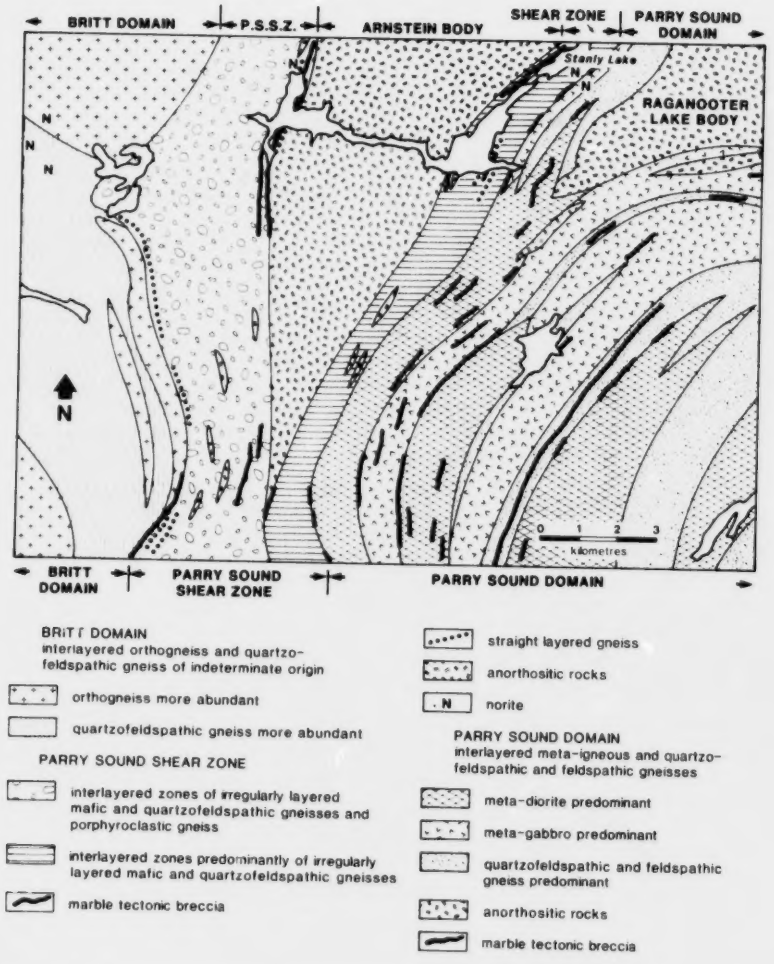


Figure 036.2. *Generalized geological map of the Ferrie River area.*

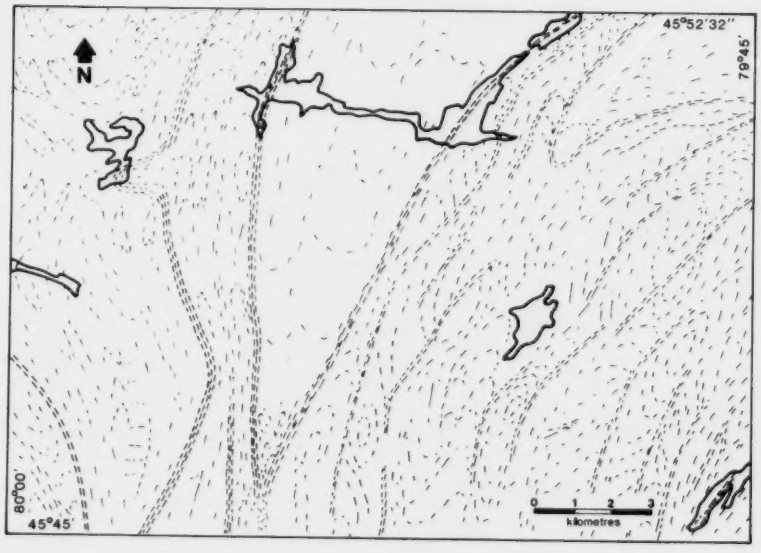


Figure 036.3. *Foliation trajectory map of the Ferrie River area.*

PARRY SOUND SHEAR ZONE

The Parry Sound Shear Zone consists of two, wide, branches of tectonically modified gneisses located west and east of the anorthositic Arnstein body. The western branch is 2 to 4 km wide and merges with the narrower northeast-trending branch south of the tail of the weakly deformed Arnstein body. Davidson *et al.* (1982) does not include the eastern branch in the Parry Sound Shear Zone.

Interlayered zones of irregularly layered mafic gneiss, quartzofeldspathic gneiss and porphyroclastic gneiss of varied width and length constitute most of the western branch. This group of gneisses are bounded locally by thinly-layered straight gneiss zones. Two zones of marble tectonic breccia along the eastern side of the western branch occur locally with straight gneiss. The eastern branch of the Parry Sound Shear Zone mainly contains irregularly-layered mafic and quartzofeldspathic gneisses with local marble breccia and straight gneiss. Small bands of anorthositic rock and bodies of non-foliated norite are locally present in both branches of the shear zone.

Fine- to medium-grained, irregularly-layered mafic and quartzofeldspathic gneisses contain varied amounts of thin to thick, commonly disrupted, granitoid bands. Fine-grained straight gneiss comprises thin, continuous layers of constant thickness and of varied composition. Porphyroclastic gneisses are characterized by variable proportions of feldspar or pegmatite clasts in a fine- to medium-grained matrix of quartzofeldspathic or pelitic composition, or both. Mafic compositions are rare. Relict igneous textures occur commonly in the Arnstein body, norites, and locally, in smaller bands of anorthositic rock.

Many quartzofeldspathic gneisses in the shear zone, particularly those bordering the Britt Domain, compositionally resemble less deformed gneisses in the Britt Domain. It is likely, as Davidson (1984b) suggested, that deformation in the Parry Sound Shear Zone has involved both Parry Sound and Britt Domain rocks.

STRUCTURAL GEOLOGY

STRUCTURAL GRAIN

Ridges and valleys in the map area tend to follow the prevailing north to northeast gneissosity orientation, particularly west of the Arnstein Body. These geographic features impart a megascopic fabric easily distinguished in aerial photographs, which is shown in the foliation trajectory map (Figure 036.3). Figure 036.3 is based on field observations and aerial photo interpretation. Commonly observed in the Britt Domain and the Parry Sound Shear Zone, but rare in the Parry Sound Domain, are metre-scale, tight to isoclinal folds with narrow hinge zones whose limbs parallel the megascopic fabric. Intensely sheared rocks also tend to be concordant to the regional grain. Similar megascopic fabric and outcrop scale structure relationships were recognized in the Gravenhurst area (Schwerdtner *et al.* 1981) where long linear fold limbs and transposed layering dominate the structural grain.

PARRY SOUND DOMAIN

The Parry Sound Domain is composed of north- to northeast-trending zones of unfoliated to moderately foliated rocks intercalated with intensely deformed zones. In the latter, the dips are moderate to the east and the rocks are foliated by a very fine gneissosity or by very regularly banded compositional layering. These northeast-trending zones are up to several kilometres long, and in the western part of the Parry Sound Domain, are commonly associated with marble breccia. In the zones of less deformed rocks, the gneissosity is defined by quartzofeldspathic lenses of various regularity and extent. The gneissosity orientation is discordant to the northeast-trending, more intensely deformed zones, and can locally describe folds and oval shapes. Similar fold structures have been observed in the Gravenhurst area (Schwerdtner *et al.* 1981) and in the Moon River area (Hanmer 1984). Outcrop scale isoclinal folds are rarely observed and are limited mainly to the intensely deformed zones. These folds are "s" or "z" asymmetric structures with shallow to moderate east-trending fold axes parallel to the lineation, which is defined by hornblende crystal and aggregate orientation and by fine scale quartzofeldspathic rods. It is best developed in the shear zones although it is also observed locally in less deformed rocks. A late penetrative foliation defined by hornblende is locally observed in dioritic and gabbroic rocks. It varies in orientation showing both discordance and concordance with the gneissosity. The significance of this late foliation has not been determined.

BRITT DOMAIN

In contrast to the Parry Sound Domain, gneissosity is well developed throughout the domain, and the dominant orientation trends northeast to northwest with shallow to moderate dips to the east (Figure 036.3). Rocks in the Britt Domain were subjected to three folding events. The first two fold events are easily recognized in biotite-rich quartzofeldspathic gneiss in the northwestern part of the map area, whereas similar structures have not been observed in the pink quartzofeldspathic gneiss probably because of the absence of marker horizons.

The earlier fold generation consists of isoclinal folds of a fine, early gneissosity. The fold limbs are commonly attenuated to completely sheared. These typically small-scale folds are only observed in very clean exposures. They are in turn refolded into larger scale, tight to isoclinal northeast- to northwest-trending folds. Along with this second fold generation is a shallowly to moderately plunging southeast mineral lineation defined by the orientation of biotite and hornblende and an axial planar gneissosity (Photo 036.1), the latter is defined by planar quartzofeldspathic biotite-hornblende bearing discontinuous lenses which may reach several centimetres in thickness but are typically less than 1 cm thick. In fold limbs where near parallelism of both gneissosities is achieved, the later axial planar gneissosity is usually the dominant or only obvious foliation. However, in the hinge zones, it is less well developed than the earlier folded gneissosity.

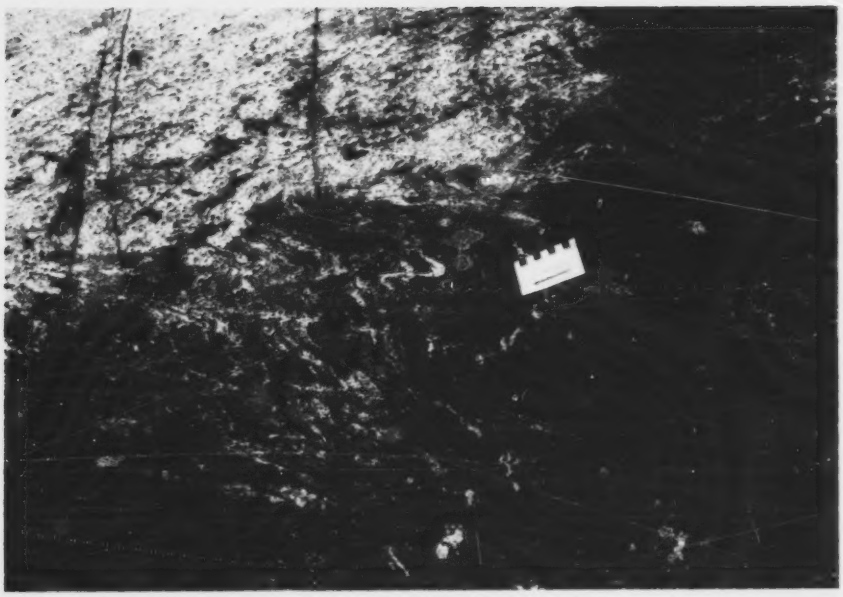


Photo 036.1. *An earlier Z-folded gneissosity is cut by a second axial planar gneissosity. Top of the photograph shows a quartzofeldspathic gneiss. A biotite-rich quartzofeldspathic gneiss is at the bottom.*

A third-fold event folds the two gneissosities into broad scale westerly-trending open structures. No associated lineation or foliation was observed.

PARRY SOUND SHEAR ZONE

Northerly, moderately east-dipping, gneissosity tends to achieve greater parallelism in this zone (Figure 036.3). The foliation plane contains an east-trending lineation defined by very fine-grained quarztofeldspathic rods. Two narrow zones of continuous, regularly banded, gneisses may contain asymmetric and isolated porphyroclasts, boudinage, greatly attenuated and rootless folds and two mineral foliations. Intercalated between these zones are strips up to 1 km in apparent thickness of very complexly folded, boudinaged, and sheared gneisses where sheared fold limbs are the prevailing structures. As proposed by Davidson *et al.* (1982), most of the movement may have been concentrated in the narrow zones of regularly banded gneisses where mainly kinematic indicators, mylonitic foliations and porphyroclasts, suggest movement to the west-northwest.

REGIONAL CORRELATION

The metamorphic, structural and lithological character of the Parry Sound and Britt Domains and the Parry Sound Shear Zone are similar in both the Ferrie River and the Whitestone Lake area to the south (Bright 1986) (Figure 036.4). Many rock units are continuous from one area to the other as is the Parry Sound Shear Zone.

ECONOMIC GEOLOGY

Mafic meta-igneous rocks may represent potential sources of platinum and palladium. One encouraging analysis from a norite body east of Stanly Lake (Figure 036.2) gives platinum values of 8 ppb and palladium values of 18 ppb (Geoscience Laborato-

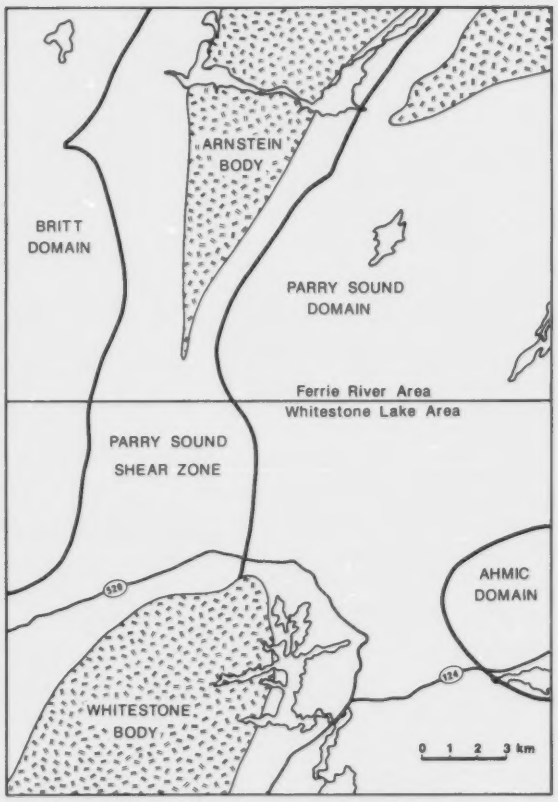


Figure 036.4. *Generalized regional geologic map of the Ferrie River and Whitestone Lake areas showing major geological boundaries.*

ries, Ontario Geological Survey, Toronto). Minor disseminated sulphide mineralization occurs locally in metagabbroic rocks of the Parry Sound Domain. The Parry Sound Domain and Parry Sound Shear Zone, with high proportions of mafic rocks, are the most favourable exploration targets for platinum and palladium mineralization in the map area.

Marmont and Johnston (1987) indicate that anorthositic rocks could be employed as a substitute for, or combination with, materials used in the rock wool, glass fibre, and glass industries. In this regard, the two large anorthositic bodies in the map area are favourable exploration targets.

Marble, found mainly as breccias within the Parry Sound Domain, represents a potential source of basic refractories and flux in the filler industry.

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037. The Precambrian–Paleozoic Unconformity in Eastern Ontario and Associated Mineralization

G. Di Prisco

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA) which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the Governments of Canada and Ontario.

INTRODUCTION

A continuing study of the Precambrian-Paleozoic unconformity in Eastern Ontario has been carried out since 1985 (Springer 1985; Churcher 1986; Di Prisco 1986). The goals of this project are to document the geology of the unconformity and to evaluate the role that it may have played in the formation of spatially associated mineralization.

Since the project began, the Madoc area has been the focus of the study. During the 1987 field season, the survey was extended further west to include a 450 km^2, northwest-trending area. Gull Lake, in Lutterworth Township, is the northwestern corner of this area and the Town of Madoc, the southeastern corner. Fifteen townships in Haliburton, Victoria, Peterborough, and Hastings Counties were investigated.

All parts of this area are easily accessible by major highways, township roads, and bush roads. The field work consisted of locating and documenting outcrops showing the unconformity, especially when mineralization was present. Road cuts and quarries, as well as some drill cores, have been the principal sources of information for this survey.

GENERAL GEOLOGY

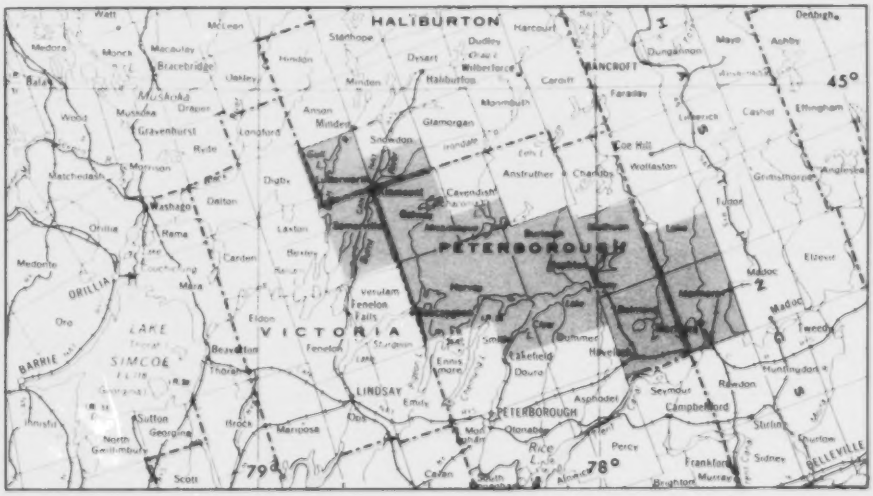
The study area lies within the central part of the Grenville Province, in which the Precambrian basement is overlain by Paleozoic sediments. The boundary between Precambrian metamorphic and igneous rocks, to the north, and Paleozoic sediments, to the south, is abrupt and unconformable. This unconformity represents a depositional gap of about 600 million years. During this period, the Precambrian land surface was subjected to a subaerial environment. Weathering and erosion of the land surface may be preserved in paleosols, karst facies, and laterisations.

PRECAMBRIAN ROCKS

Wynne-Edwards (1972) divided the Grenville Province into several major geological subdivisions, including the Central Metasedimentary Belt (CMB), where this study was undertaken. Lithostratigraphic units of the Central Metasedimentary Belt were grouped by Wynne-Edwards (1972) to form the Grenville Supergroup, which is a "...major Middle Proterozoic accumulation of supracrustal rocks...." (Easton *et al.* 1986). The supergroup consists of the Hermon, Mayo, and Flinton Groups. The Hermon and Mayo Groups are composed mainly of metamorphosed volcanic and carbonate sedimentary rocks with intercalated siliceous clastic units. The Flinton Group, which unconformably overlies the Hermon and Mayo Groups, is predominantly quartz arenite, conglomerate and other calcareous and non-calcareous metasedimentary rocks, as well as marbles (Carter 1984).

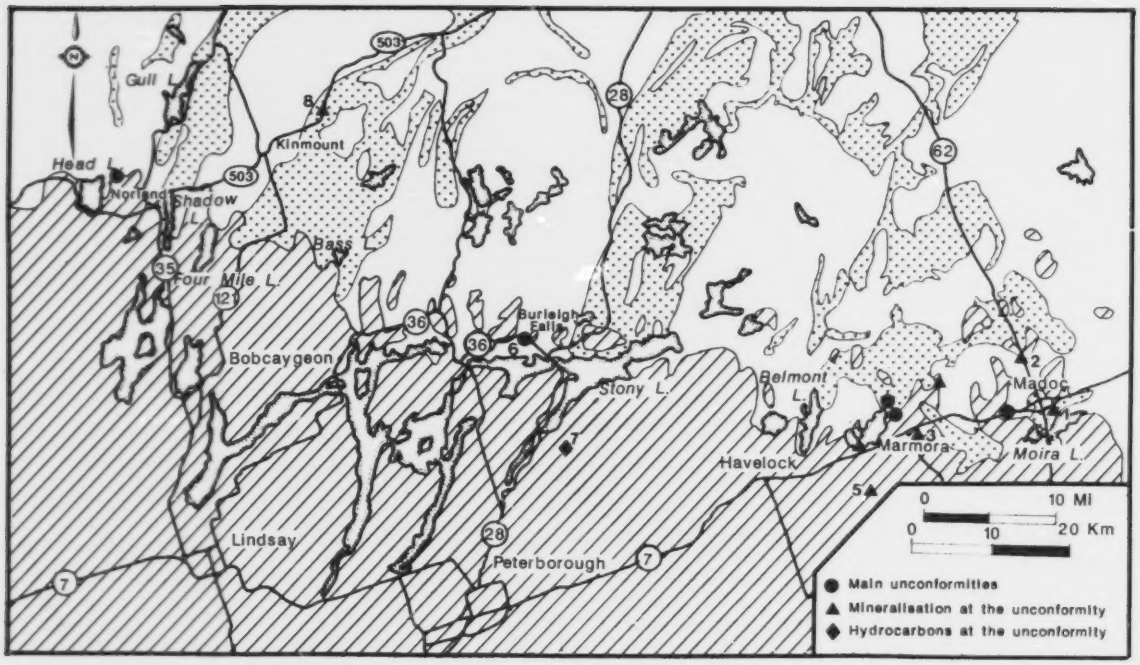
PALEOZOIC ROCKS

The Paleozoic occurs south of the unconformity boundary. Only very rare inliers of Precambrian rocks disrupt the uniformity of the Paleozoic sedimentation.



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles



1.Canadian Talc LTD , Madoc – 2. Wallebridge Iron Mine – 3. Marmoraton Iron Mine – 4. Blairton Iron Mine – 5. Trent River , Allan Mills – 6. HW 36 – 7. Stony L. Road – 8. Furnace Falls laterite

Figure 037.1. *Distribution of the Precambrian-Paleozoic unconformity in Eastern Ontario and location of major exposures of the unconformity. Location numbers correspond to those in Table 037.1.*

In the study area, the Paleozoic lithostratigraphic units are grouped into the Basal and Simcoe Groups. The Basal Group is represented in the study area by the Cambro-Ordovician Shadow Lake Formation, which lies unconformably on the Precambrian basement. This formation consists of red conglomerate, red and green sandstones, siltstones and shales, with minor interbedded limestones in the upper part. The Simcoe Group comprises, in ascending order, the Gull River, Bobcaygeon, Verulan, and Lindsay Formations, which are mainly limestones and shales, with minor dolostones.

The boundary between the Basal and Simcoe Groups is not easily identified. This difficulty is a result of the wide diversity of lithologies present as the basal unit on the basement, deposited at different times and in varying environments. However, according to Carson (1981): "The upper contact of the Shadow Lake Formation with the Gull River Formation is defined as the last appearance of clastic sedimentary units and the beginning of virtually continuous carbonate units..... Therefore, the Shadow Lake-Gull River boundary essentially represents a change from unstable to stable depositions of conditions."

UNCONFORMITY EXPOSURES AND ECONOMIC IMPLICATIONS

UNCONFORMITY EXPOSURES

Based on the results of previous studies (Di Prisco 1986), it seemed that the most favourable areas for mineralization were the zones of contact between Precambrian carbonate rocks and the basal series of the Paleozoic. Thus, for the first stage of the 1987 survey, three such zones were selected: the first, north of Madoc and Marmora; the second, north of Stony Lake and Burleigh Falls; and the third, the north side of Bass, Four Mile, and Shadow Lakes (Figure 037.1).

In its second stage, the survey was extended to encompass the entire area, from Madoc in the east to Norland and Head Lake in the west.

Finally, some drill cores showing the unconformity were examined in the Drill Core Library, Ontario Ministry of Northern Development and Mines, Tweed.

Several exposures of the unconformity, including some previously unreported, were examined. Of these, only a few showed signs of mineralization.

TABLE 037.1. CHARACTERISTICS OF SELECTED OUTCROPS IN THE STUDY AREA.

No.	Name	County	Township	Latitude	Longitude	Precambrian Rocks	Paleozoic Rocks	Other Observations
1	Canada Talc, Limited	Hastings	Huntingdon	44°30'10"	77°27'13"	Calcitic and dolomitic marbles, showing a hydrothermal alteration. In places, karst exposures.	Greenish and reddish sandstones rich in quartz fragments; shales and limestones.	Syngenetic sulphide mineralization occurs in the greenish sandstones which fill the karst cavities. Crusts of hematite on the surface of the marbles.
2	Wallebridge Iron Mine	Hastings	Madoc	43°33'47"	77°30'32"	Calcitic marbles with disseminated lenses of hematite; minor magnetite. Weathered zone above the marbles.	Reddish coarse sandstones and shales rich in quartz fragments, overlain by sandy limestones.	Presence of a gossan on the top of the marbles. The iron oxides are remobilized and cement the basal Paleozoic sandstones.
3	Marmoraton Iron Mine	Hastings	Marmora	44°28'44"	77°39'29"	Intrusion of syenite into Grenville marbles. Skarn iron ore deposit.	Reddish conglomerate, sandstones and shales, and sandy clastic limestones. Abundance of quartz fragments up to 1 m.	Clasts of magnetite (up to 3 cm) are present in the basal Paleozoic sandstones, above the ore deposits.
4	Blairton Iron Mine	Peterborough	Belmont	44°29'02"	77°45'21"	Intrusion of gabbro-diorite in carbonate meta-sediments. Skarn iron ore deposit.	Dark reddish conglomerate and shales rich in quartz fragments, overlain by clastic limestones.	Presence of a gossan on the top of the mineral deposit. Fragments of hematite and magnetite up to 15 cm are present in the basal Paleozoic.
5	Trent River A, Allan Mills, Drill Core TWO 311	Peterborough	Seymour	45°24'39"	77°43'00"	Carbonate metasediment.	Greenish, reddish conglomerate and sandstones. Quartz fragments.	Abundant clasts of magnetite and hematite up to 4 cm, just above the Precambrian surface.
6	Highway 36, West of Burleigh Falls	Peterborough	Harvey	44°34'56"	78°15'19"	Granitic gneiss.	Greenish sandstone, reddish shales and sandy limestones, micritic limestones. Abundant quartz fragments.	Paleosol up to 50 cm thick is present between the Precambrian rocks and the Paleozoic sandstone.

The locations of the exposures are shown in Figure 037.1 and observations from selected outcrops are summarized in Table 037.1.

Point 7 on Figure 037.1 (Latitude 44°27'29"N, Longitude 78°12'21"W) represents an inlier of Precambrian granite. The peculiarity of this outcrop lies in the fact that traces of hydrocarbons are found trapped between the thin laminae of the Paleozoic limestone. Crystals of pyrite are also present with the hydrocarbon.

ECONOMIC IMPLICATIONS OF THE UNCONFORMITY SURFACE

Field evidence shows that the unconformity is a favourable zone for mineralization and the economic implications of the unconformity surface need no further demonstration. The existence of gossans of iron oxide has long been known; for example, the Coe Mine was one of the first iron mines of the region (Hewitt 1968). Other deposits, such as the Wallebridge Iron Mine, were used as a source of iron-oxide pigments. More promising would be a new discovery of free gold in gossans as cited by Springer (1985): "...the Richardson Mine in Madoc Township (Vennor 1870) and the Cordova Mine in Belmont Township (Blue 1894) were found to contain spectacular coarse gold values in ferruginous earths above the sulphide ores." A laterization of the Precambrian surface seems to occur in some places in the carbonate metasediments: (Easton 1987) described one of these (Number 8 on Figure 037.1). Geochemical analyses of these carbonate metasediments show a content of Fe_2O_3 up to 25%.

Karst infillings by Paleozoic clastic sediments are also favourable places where syngenetic sulphide mineralization could occur. Outcrop at the Canada Talc Limited Quarry in Madoc provide a good example of such mineralization (Di Prisco 1986). In other outcrops, clasts of iron ore, mainly hematite and magnetite, occur in the earliest clastic Paleozoic sediments. These mineralized fragments are always very close to pre-existing ore deposits (e.g. Wallebridge Iron Mine, Marmoraton Iron Mine, Blairton Iron Mine). However, the quantity of the iron ore fragments is not in itself sufficient to constitute an ore deposit. They are, nonetheless, a clear guideline for exploration, signalling the high probability of the close presence of an ore deposit in the Precambrian basement. This guideline for iron exploration might also be useful in locating other base metals such as copper and zinc, as well as gold. The basal clastic units of the Paleozoic have never been considered as potential paleoplacers. However, the discovery of gold mineralization, much more than base metals, could lead to small, but viable, exploitations.

SUMMARY

About 600 million years separate the last Precambrian event from the first clastic deposits of the Paleozoic in Eastern Ontario. During this hiatus, the Precambrian land surface was subjected to a subaerial environment. Paleosols, karst features, laterites, and gossans on the Precambrian surface were trapped underneath the Paleozoic, and attest to the diagenetic processes. Supergene enrichments of iron and gold occurred on the paleosurface, which is still a target for such mineralization.

The Central Metasedimentary Belt is a favourable location for stratiform zinc and polymetallic zinc, lead, copper, silver, and gold deposits. A geochemical survey of the unconformity surface above carbonate metasediments could lead to the discovery of new deposits.

Finally, the earliest clastic deposits of the Paleozoic represent, in some cases, clear guidelines for mineral exploration and could constitute by themselves, in some favourable locations, economically viable deposits of precious metals.

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Commodity Studies

MAFIC INTRUSIVE ROCKS AND THEIR MINERALIZATION

INDUSTRIAL MINERALS

038. Investigations of the Geology of the Platinum Group of Elements in Ontario

A. James Macdonald

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto

INTRODUCTION

In response to anticipated global interest in, and demand for, the Platinum Group of Elements (PGE), the Ontario Geological Survey (OGS) initiated a program in 1984 designed to investigate the geology and potential of PGE within the Province. During 1986, interest in the PGE within the Canadian mining community increased considerably, with most activity occurring in the Thunder Bay Mining District of Northern Ontario. Investigations by the OGS into the geology of the PGE in Ontario were expanded in 1987 to include studies elsewhere in the Province, and to assemble a comprehensive database of PGE occurrences and potential host rocks.

Preliminary studies by OGS geoscientists are reported in the Summaries of Field Work and Other Activities for 1985 and 1986 (Ontario Geological Survey, Miscellaneous Papers 126 and 134).

FIELD STUDIES IN 1987

The Werner-Rex Lakes area in Northwestern Ontario may contain an extension of the Bird River Greenstone Belt in Manitoba. A number of mafic and ultramafic intrusions are localized within fault zones in the Werner-Rex Lakes area, and are host to significant Cu-Ni-PGE occurrences and past-producing mines. In 1987, Lawson and Zuberec (this volume, article 041) commenced an investigation of the area, concentrating on the area in the immediate vicinity of Werner and Gordon Lakes.

Ontario Geological Survey mapping of the Lac des Iles complex continued in 1986 and 1987 (Macdonald and Lawson, this volume, article 040; Sweeny, M.Sc Thesis, in preparation). Linhardt continued his study of the Northern Ultramafic Complex at Lac des Iles as part of a Ph.D Thesis (Linhardt and Bues, this volume, article 044).

The Proterozoic Crystal Lakes gabbro, southwest of Thunder Bay, is host to an economically interesting Cu-Ni-PGE mineralization, also known as the Great Lakes Nickel Occurrence. The geology of the Crystal Lakes intrusion and surrounding area is being investigated by Smith and Sutcliffe (this volume, article 039) in 1987.

The Abitibi Greenstone Belt is host to past-producing Cu-Ni ores in mafic and ultramafic rocks. A program was commenced in 1987 to investigate the PGE potential of the Abitibi Belt, with an emphasis in the Timmins, Kirkland Lake, and Temagami areas (two articles by Good, this volume, articles 042 and 043).

Conrod (this volume, article 045) describes silver, cobalt and nickel mineralization within Nipissing Diabase of the Southern Province, in the Cobalt and Gowganda areas, and is completing a Master of Science Thesis on the PGE potential of some of these rocks.

The PGE potential of the Grenville Province has perhaps been insufficiently emphasized during the past. The Grenville Province contains considerable volumes of mafic and ultramafic intrusive rocks, with scant data on their PGE contents. Accordingly, in 1987, Wilson (in preparation) began an evaluation of the geology and PGE potential of mafic and ultramafic rocks in the Grenville Province, while Garland (this volume, article 046) is investigating the platinum group and gold distribution within the Central Gneiss Belt, in the vicinity of Parry Sound and Muskoka.

Several non-traditional occurrences of the PGE have been described in the last decade in host rocks that do not conform to the typical mafic/ultramafic associations. These include black shales (Kucha 1982), carbonatites (Verwoerd 1986), porphyry copper deposits associated with alkaline stocks (Finch *et al.* 1983), uraniferous veins associated with mafic intrusions (Hulbert 1986), and epithermal Au-PGE veins (Needham and Stuart-Smith 1987).

In order to avoid the investigation of PGE potential being restricted solely to the classical mafic/ultramafic associations, the Ontario Geological Survey initiated a program in 1987 to perform PGE assays on samples selected from the PETROCH database, consisting of rock powders from samples collected by OGS geologists over the last several years, but not previously assayed for PGE. Of particular interest in this study are samples containing Cu(+Ni) sulphides within alkaline host rocks, such as carbonatites. This portion of the program is designed to test whether previously undescribed geological environments within the Province may provide significant PGE resources.

The Ontario Geological Survey is preparing a compilation of PGE deposits in Ontario, and considerations of PGE potential throughout the whole Province (Macdonald and Cherry, in preparation), to which both government and industry geologists have contributed.

To date, the OGS PGE program has comprised detailed geological mapping of a number of mineralized occurrences, some preliminary geochemical and geophysical investigations, and a compilation of known PGE showings, with descriptions of their host rocks. Ongoing investigations are designed to provide an assessment of PGE potential within Ontario, based upon a geological understanding of PGE mineralization and upon techniques applicable to exploration for these deposit types.

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039. Keweenawan Intrusive Rocks of the Thunder Bay Area

A.R. Smith and R.H. Sutcliffe

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

This summary presents the preliminary results of regional geological mapping of Proterozoic intrusive rocks along the northern shore of Lake Superior. Three areas, near Crystal Lake (NTS 52 A/3 and 52 A/4), Moss Lake (NTS 52 A/9), and the east side of St. Ignace Island (NTS 42 D/12 and 42 D/13), were mapped at a scale of 1:50 000. In addition, a more detailed mapping (1:7 920 scale) of the Crystal Lake Gabbro (NTS 52 A/3) was completed. Emphasis in this report is on the Crystal Lake Gabbro and the immediately surrounding area.

Regional mapping has established the tectonic setting, lithological diversity, and characteristic mineralization of the intrusive rocks. The mapping also provides a framework for understanding the petrologic evolution of basaltic magmas, which may allow further refinements of understanding of the tectonic evolution of the Keweenawan rift system in the Lake Superior area.

LOCATION AND ACCESS

The Crystal Lake area is centred approximately 40 km southwest of Thunder Bay. The area mapped includes most of Devon, Pardee, and Crooks Townships, and the southern margins of Fraleigh, Pearson, and Blake Townships (NTS 52 A/3 and 52 A/4). The area is accessible from Thunder Bay by travelling south on Highway 61. A network of all-weather highways and logging roads provides access to outcrop on the mainland. Exposures on the north shore of Lake Superior and on the offshore islands are accessible by boat from Pine Bay and Cloud Bay.

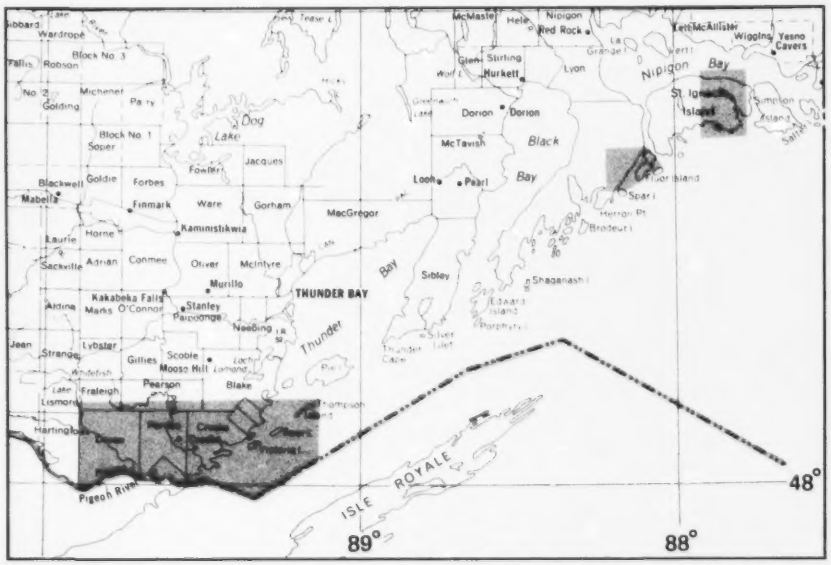
MINERAL EXPLORATION

Economic interest in the Crystal Lake area was initially for silver, barite, copper, and nickel. Information on mineral exploration reported here, unless otherwise indicated, is taken from the Assessment Files Research Office, Ontario Geological Survey, Toronto.

Silver was first discovered in the area during the mid-1800s by the Montreal Mining Company. It was eventually mined from large calcite-barite veins at the Jarvis Island Mine, Spar Island Mine, and the Prince Mine (on the north shore of Lake Superior, southwest of Jarvis Point) (Figure 039.1). Barite was also recovered during this time from zoned calcite-barite veins on Jarvis Island and McKellar Island. Silver and barite production was eventually suspended as a result of diminishing grades and deposit size. Further exploration efforts in the early to mid-1900s failed to define any economic deposits of silver or barite.

Copper and nickel were reportedly discovered at the turn of the century in gabbroic boulders along the west border of Pardee Township by J.A. McCuaig. Prospecting activities in the early 1900s to determine the source of these mineralized boulders led to the discovery of the Great Lakes Nickel Deposit in the Crystal Lake Gabbro.

Extensive exploration work was completed on this property between 1952 and 1986 by Mattawin Gold Mines, Falconbridge Nickel Mines Limited, Mo-



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

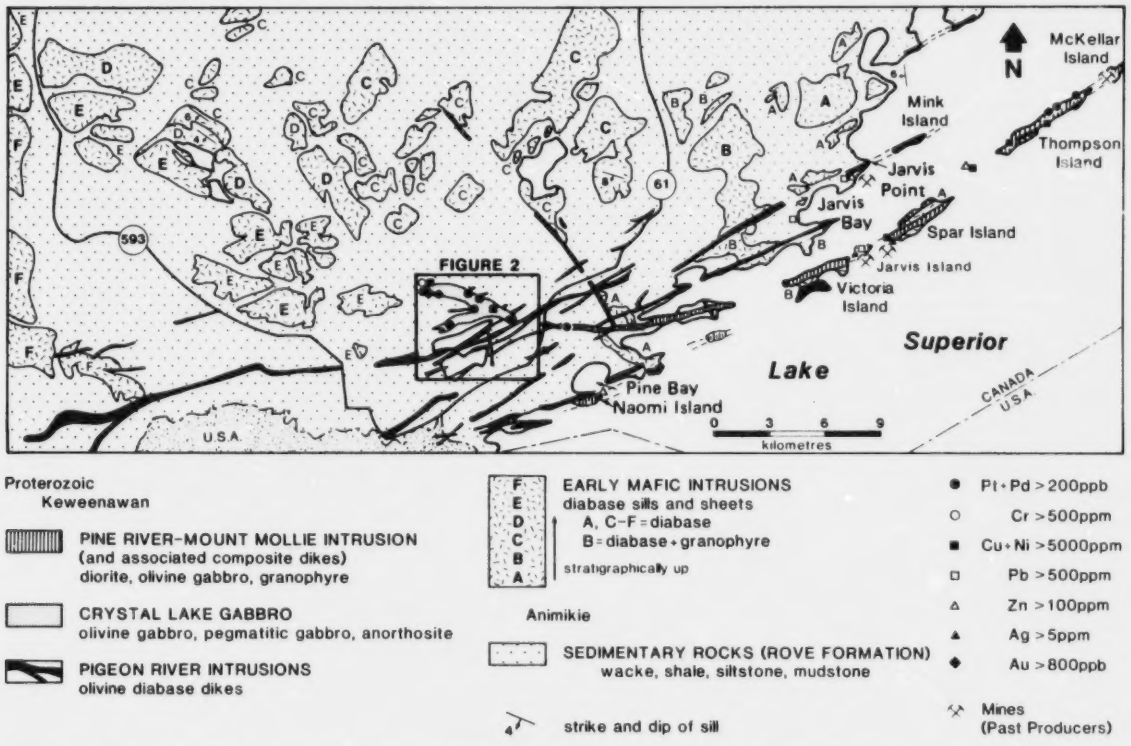


Figure 039.1. *Geological diagram showing location of the Keweenawan Intrusive Rocks of the Thunder Bay area.*

gul Mining Corporation, Great Lakes Nickel Corporation, Fleck Resources Limited, and several individual prospectors. Surface and underground diamond drilling outlined a large-tonnage low-grade copper-nickel deposit which contains low-grade platinum group element (PGE) values (*see* Economic Geology).

The discovery of PGE mineralization within the Crystal Lake Gabbro in 1986 renewed exploration interest in the area. Numerous small copper-nickel occurrences have been outlined in diabase dikes and in the Pine River-Mount Mollie Intrusion since 1952. Recent claim staking and prospecting activity has centered on the evaluation of these occurrences for PGEs.

GENERAL GEOLOGY

The Crystal Lake area was first mapped on a reconnaissance scale (1:63 360) by Tanton (Tanton 1936a, 1936b, 1936c). The area is included on ODM Geological Compilation Map 2065 (Pye and Fenwick 1965) and on ODM Preliminary Map 177 (Pye and Fenwick 1963, 1965). More recent maps and geological reports were completed by Geul at a scale of 1:31 680 (Geul 1970, 1973).

The area lies within the Southern Province of the Canadian Shield. The Proterozoic rocks exposed in the area form a nearly unmetamorphosed cratonic cover over essentially unexposed Archean rocks of the Superior Province.

Early Proterozoic (Aphebian) sedimentary rocks in the area consist of arenaceous and argillaceous units of the Rove Formation. Shales, siltstones, and mudstones predominate in the lower part of the formation, and wackes with argillaceous interbeds are abundant near the top. Thin quartzite beds (10 to 20 cm thick) were found in the central part of the study area, in the upper part of the sedimentary sequence. A single, 20 cm thick limestone bed was discovered in the south central part of the area, just north of the Pigeon River.

Middle Proterozoic (Neo-Helikian) age rocks intrude sedimentary units of the Rove Formation. These rocks represent the first of three major intrusive events in the Crystal Lake area. Sills and sheets of diabase and granophyre dip gently southwestward and form large cuestas which protect the underlying sedimentary rocks from erosion. The sills are characterized by reversed magnetic polarity and are probably correlative with sills in the Nipigon area, which have been dated at 1108.8^{+4}_{-2} Ma by Davies and Sutcliffe (1985) using the U-Pb zircon method. The diabase sills in the Thunder Bay area may also be correlated with reversely polarized diabase sills in the Duluth, Minnesota area (Weiblen 1982). As in the Nipigon area, the Thunder Bay sills were intruded at an early stage of Keweenawan rifting.

The sills are primarily fine- to medium-grained, equigranular tholeiitic diabase. They exhibit chilled contact zones against the host sedimentary rocks,

the latter of which display only weak, or no, contact metamorphism. Both mineralogical and textural variations were observed within vertical sill sections. Typical sections are characterized by a narrow (millimetres to a few centimetres thick) basal, aphanitic to fine-grained chill zone which grades upward into fine-grained ophitic diabase. A fine- to medium-grained diabase, with medium- to coarse-grained plagioclase phenocrysts to megacrysts, often composes the central portion of a sill. This porphyritic diabase grades upward into a medium- to fine-grained, iron oxide-rich diabase, which displays extensive oxidation weathering where it is exposed on surface.

The composite Jarvis sill (sill B on Figure 039.1) is composed of a chill margin, a lower zone of diabase which grades upward into plagioclase- and pyroxene-porphyritic altered diabase, and an uppermost hematized granophyre. The diabase at the base of the sill varies from less than 0.5 m thick on Victoria Island, to 5.0 m thick along the north shore of Lake Superior.

Additional megascopic features observed within the sills include well-developed vertical columnar jointing, wispy leucocratic lenses and layers, and rare sedimentary rock inclusions.

Six major sills (those greater than 5 m thick) were traced throughout the study area and arranged in stratigraphic succession. The thickest sills (44 m thick) occur in the northwestern part of the map area.

Both the intrusive Keweenawan sills and the sedimentary rocks of the Rove Formation are cut by a series of linear olivine diabase and quartz diabase dikes, which are steeply dipping and trend east-northeast to northeast. These dikes, which are generally referred to as the Pigeon River series, represent the second major intrusive event in the Crystal Lake area (Figure 039.1). Dikes average 50 to 70 m in thickness, but may be as much as 150 m thick. They can be traced semicontinuously for up to 15 km along strike.

While some dikes clearly crosscut sills, others show less distinct relationships and appear to merge with the sills. In some cases, it is possible that a sill restricted the vertically-upward emplacement of a later dike. Horizontal columnar jointing is well developed in some dikes. The presence of multiple patterns of columnar jointing over a small area suggests the occurrence of multiple or composite dikes.

Two types of contacts have been observed between the diabase dikes and the sedimentary rocks. Most commonly, the contact is characterized by a margin (usually less than 5 cm thick) of aphanitic to fine-grained, chilled diabase. However, many dikes lack this sharp chilled contact, and instead are characterized by fine- to medium-grained, hematized, dioritic to syenitic margins, which are 0.5 to 1.0 m thick and contain xenoliths of partially assimilated wacke and shale. Granophyric patches are locally present in the contact zone. Alteration, consisting of uralitization, carbonatization, and saussuritization, appears to be more pervasive in the marginal zones. Contact metamorphism of the host sedimentary rock is minimal and is restricted to baked hornfels zones less than 10 cm wide.

Variations in grain size and texture of diabase occur in the dikes. Fine- to medium-grained ophitic diabase and medium-grained isogranular diabase are the two most common varieties. Plagioclase-porphyritic, -glomeroporphyritic, and -megacrystic diabase occur most frequently in the cores of the dikes. Other megascopic features noted in the dikes include pegmatitic patches, leucocratic segregations, sulphide mineral pods, and granitic inclusions.

One major northwest-trending diabase dike can be traced intermittently for 15 km in the central part of the map area. A mineralogically and texturally similar 2 km long north-northwest-trending dike occurs south of the Crystal Lake Gabbro. These two dikes appear to both locally crosscut and be cut by olivine diabase dikes of the Pigeon River series, with which they are considered contemporaneous.

The third major intrusive event recorded in the area mapped is the emplacement of the Crystal Lake Gabbro and the Pine River-Mount Mollie Intrusion. These intrusions postdate the emplacement of both the diabase sills in the Thunder Bay area and the Pigeon River olivine diabase dikes.

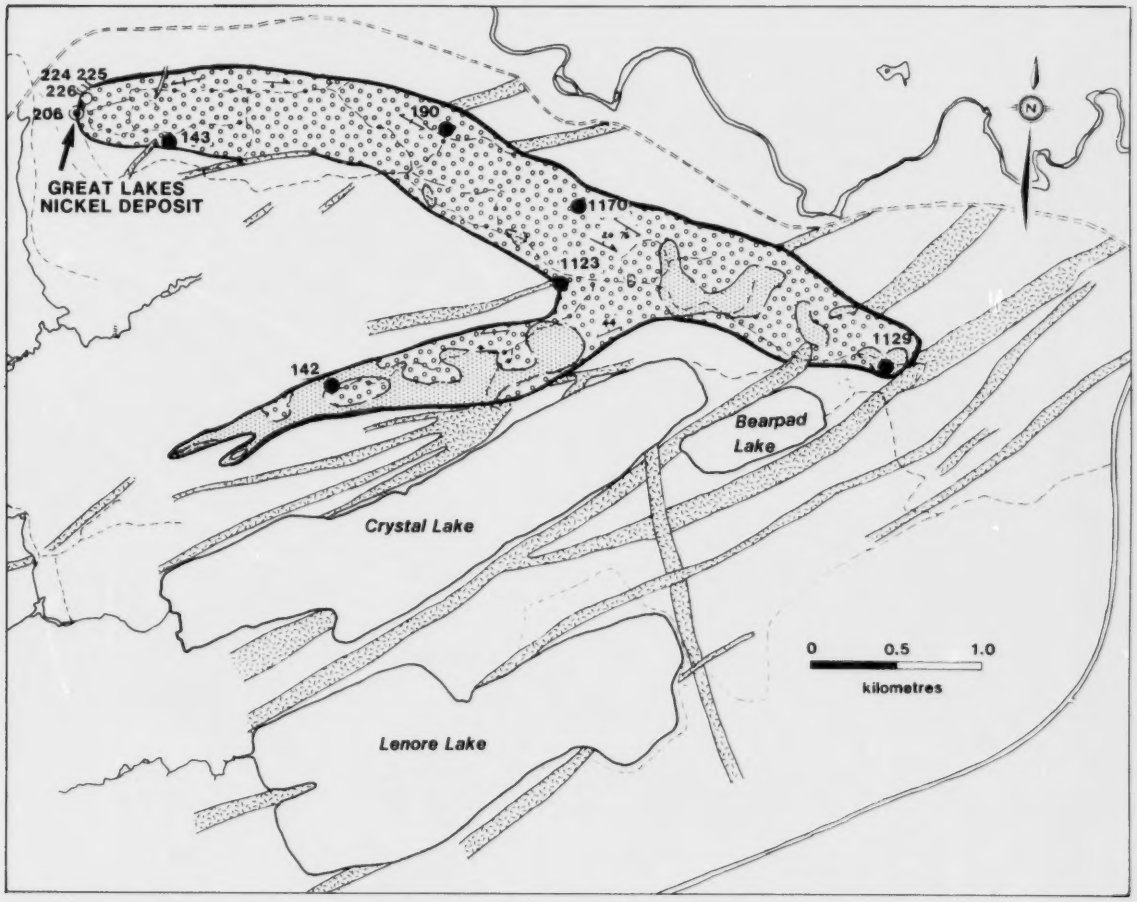
CRYSTAL LAKE GABBRO

The geology of the Crystal Lake Gabbro has previously been described by Geul (1970) and Whittaker (1986). The intrusion was mapped at a scale of 1:7 920 during the 1987 field season to determine the variability of lithologies within it, to document the igneous stratigraphy, and to determine the distribution of copper, nickel, and PGE mineralization.

The intrusion is approximately "Y" shaped and can be divided into a 5 km long, west-northwest-striking north limb, and a 2.75 km long, east-northeast-striking south limb (Figure 039.2). Measurements of layering and foliation suggest that the surface geometry may result from a tilted cone shape open on the western end.

The Crystal Lake Gabbro exhibits fresh primary igneous mineralogy despite its Proterozoic age. Gabbroic rocks in the intrusion are variable in mineralogy and texture. These rocks are cumulates, with plagioclase, olivine, and clinopyroxene being the main cumulus phases, and iron oxide minerals, copper-nickel sulphide minerals, clinopyroxene, and plagioclase occupying intercumulus spaces. Four major lithological zones were observed in the north limb of the intrusion: the Basal, Lower, Middle (Layered), and Upper Zones.

The Basal Zone, which comprises chilled, aphanitic to fine-grained gabbro, is in contact with argillites and wackes of the Rove Formation at the base of the intrusion. Angular inclusions of sedimentary rocks are contained in this chilled border phase, which has a maximum thickness of 7 m. Where chilled gabbro cuts dikes of Pigeon River diabase in the sedimentary rocks, oval diabase inclusions occur in the gabbro. Some Pigeon River dikes project into the gabbro and may have acted as a partial dam to emplacement of the gabbroic magma. These projections therefore do not intrude the gabbro, but rather are competent remnants of dikes which were at some time stoped away by the gabbro.



Middle Proterozoic

Crystal Lake Gabbro

olivine gabbro, troctolite

gabbro, leucogabbro, pegmatitic gabbro, anorthosite

diorite

chilled gabbro

Pigeon River Dikes

olivine diabase

Early Proterozoic

Rove Formation

argillite, wacke

layering (strike dip)

foliation (strike dip)

lithological contact

adit

roads

sulphide mineralization with > 5000 ppm Cu + Ni

sulphide mineralization with > 200 ppb Pt + Pd

sulphide mineralization with > 500 ppm Cr

Figure 039.2. *Location and geology of the area surrounding the Great Lakes Nickel Deposit.*

The Basal Zone is succeeded upward by a medium- to coarse-grained gabbro, here referred to as the Lower Zone. The Lower Zone is 60 m thick. Abundant patches of gabbro pegmatite and blocks of leucotroctolite occur in the lower half of the Lower Zone. The copper-nickel ore zone of the Great Lakes Nickel Deposit, which is composed of abundant blebs and disseminations of chalcopyrite, pentlandite, and pyrrhotite, also occurs in the lower part of the Lower Zone. The upper part of the Lower Zone contains segregations of coarse-grained to pegmatitic, leucogabbro to anorthosite containing less than 5 percent disseminated chromite. These chromite

"pods" are elliptical, and tend to be elongate parallel to the layering.

The Middle, or Layered, Zone is 25 m thick. It marks the beginning of distinct phase layering. Anorthosite layers, chromite-bearing anorthosite layers, and gabbro layers alternate in an intermittent layering pattern. Chromite comprises up to 40 modal percent of narrow anorthositic layers and also occurs disseminated in the rock surrounding these layers.

The Upper Zone comprises coarse-grained olivine gabbro and an overlying medium-grained troctolite. These lithologies are separated by a gradational contact. The Upper Zone is approximately 80 m thick. Wispy to intermittent modal layering, defined by changes in the modal concentrations of plagioclase, pyroxene, and olivine, is locally developed in the Upper Zone. Other megascopic features observed in the troctolite include a local strong foliation of plagioclase and lensoid pegmatitic patches oriented parallel to the foliation.

PINE RIVER–MOUNT MOLLIE INTRUSION

A major composite dike, here called the Pine River-Mount Mollie Intrusion, extends from the western edge of Crooks Township in the west to McKellar Island in the east. The intrusion, which is 60 to 350 m wide, can be traced intermittently for 35 km. It varies in composition from gabbro through diorite to granophyre, with mafic phases being most abundant in the eastern end and in the core of the intrusion. Textures indicative of the mixing of mafic and felsic magmas occur in this intrusion.

Medium- to coarse-grained gabbro and olivine gabbro, locally exhibiting steeply-dipping modal layering, are abundant. Patches of pegmatitic gabbro and pods containing massive sulphide mineralization are abundant along the margins of the intrusion. With increasing hornblende and quartz content, the gabbro grades into diorite. Diorite varies from fine to coarse grained, is often hematized, and contains numerous miarolitic cavities. Round patches and elongate schlieren of diorite containing skeletal amphiboles exhibit mixing textures with the host gabbro. Rounded to subangular inclusions of sedimentary rock, and pillow-shaped mafic inclusions occur locally in the diorite.

A felsic phase consisting of fine- to medium-grained hematized granophyre often forms the margin of the dike. This rock contains abundant quartz, alkali feldspar, and miarolitic cavities. It occurs in both gradational (greater than 2 m) and sharp (2 cm) contact with the diorite. The gradational contact contains net-textured patches of granophyre matrix surrounding microdiorite.

A zone of brecciation exposed on McKellar Point (west-southwest of Victoria Island, on the north shore of Lake Superior) provides evidence of the explosive emplacement of the felsic phase. Outcrops in this breccia zone are composed of up to 60 percent angular inclusions of sedimentary rock and less abundant, subangular to rounded, mafic dioritic inclusions in a fractured calcite-bearing granophyric matrix.

The Pine River-Mount Mollie Intrusion, although not spatially associated with the Crystal Lake Gabbro, is probably in part contemporaneous with it. It may have formed from the same magma reservoir, with the Crystal Lake Gabbro representing an early accumulation of mafic magma and the Pine River-Mount Mollie Intrusion representing magma from the same reservoir, which has both mixed with and been later intruded by intermediate to felsic melts.

STRUCTURE AND ALTERATION

The study area is on the north limb of the Lake Superior Geosyncline, which formed during the Keweenawan rifting event. The gentle southward dips of the Rove Formation and of the sills of the Thunder Bay area reflect this tectonic setting. Emplacement of the Keweenawan mafic intrusive rocks was localized by a large fracture-fault zone which parallels the north shore of Lake Superior, trending 065°.

Major lineaments parallel the northeasterly-trending Pigeon River dike swarm. A relatively consistent pattern of upwarping of sedimentary rock beds against the steeply-dipping south sides of the Pigeon River dikes was observed. This upwarping probably reflects normal faulting along the fracture zones prior to dike emplacement. Slickensides on some dike-sedimentary rock contacts suggest later reactivation of the faults.

A secondary fracture set perpendicular to the major set localized the north-northwest-trending diabase dikes. Small-scale faulting associated with this fracture set has produced local graben blocks. The bounding faults of the blocks are tens of metres apart and have vertical displacements ranging from 1 to 10 m. This secondary fracture set also served as a zone of weakness along which metre-scale late-stage barite-calcite veins were emplaced. These veins strike between 140° and 165° and dip subvertically.

Deformation in the area is minor, with only slight tilting and warping of sill-sedimentary rock sequences. Sills are for the most part conformable, but they do pinch and swell along strike and locally cut the underlying sedimentary rocks. In cross-section, a lobe of one sill on Spar Island appears to terminate in interbedded wacke and argillite. North of the Crystal Lake Gabbro, a series of oval diabase bodies appears to be conformable with interbedded wacke and argillite. It may be that these features represent stages in the growth of sills, the oval bodies being remnant finger-like projections of mafic magma. At a further stage in sill growth, these fingers might coalesce to form continuous sheets in a manner similar to that suggested by Pollard *et al.* (1975).

Although feeders for the large sills were not recognized, a feeder for one of the small sills was identified in a quarry north of the Crystal Lake Gabbro. Here, a 3 m wide, near vertical diabase dike, projecting through sedimentary rocks, turns to a horizontal attitude and forms a 1.5 m wide sill near the top of the exposed section.

TABLE 039.1 ASSAY VALUES FOR SAMPLES FROM THE CRYSTAL LAKE GABBRO

Sample No	Rock Type	Pt (ppb)	Pd (ppb)	Cu (ppm)	Ni (ppm)	Au (ppb)	Ag (ppm)	Pb (ppm)	Zn (ppm)	Cr (ppm)
206	pegmatitic gabbro	95	7810	9700	1900	210				
226	anorthosite	70	360	575	710					4.04%
224	chromite layers			148	850					720
225	chromite layers									3.2%
143	olivine gabbro	69	150	2080	1600	35				
1123	olivine gabbro	78	220	3140	1360	37				
1170	olivine gabbro	78	270	2770	500	33				
1214	olivine gabbro	115	120	1310	880	30				
1129	coarse-grained gabbro	125	340	2990	1420	45				
190	chilled gabbro	60	300	1820	940	27				
198	porphyritic gabbro	55	280	3270	1100					
142	coarse olivine gabbro	145	170	2500	1320	39				

ECONOMIC GEOLOGY

Mineral occurrences in the Crystal Lake area include the platinum group elements, copper, nickel, chromium, silver, barium, lead, zinc, and gold. Despite the many occurrences, economic deposits have not yet been identified.

The Crystal Lake Gabbro is the most important exploration target in the area. This intrusion hosts the Great Lakes Nickel Deposit, a large-tonnage low-grade copper-nickel deposit, which is known to also contain low-grade PGE values (Figure 039.2). The most recently published grades available for the deposit are 0.334 percent copper, 0.183 percent nickel, 0.02 ounce palladium per ton, 0.006 ounce platinum per ton, 0.0004 ounce rhodium per ton, 0.002 ounce gold per ton, and 0.06 ounce silver per ton (Postle *et al.* 1986).

Anomalous PGE values were obtained from samples collected from the Crystal Lake Gabbro during the current project. The copper-nickel ore zone, located near the base of the Lower Zone, contains magmatic sulphide mineralization in the form of chalcopyrite, pyrrhotite, and pentlandite. A sample of pegmatitic gabbro from this zone returned values of 9700 ppm copper, 1900 ppm nickel, 7810 ppb palladium, 95 ppb platinum, and 210 ppb gold (Sample 206, Table 039.1).

Anomalous PGE values were also obtained from chromite-bearing anorthositic gabbro, stratigraphically above the copper-nickel ore zone. Grab samples of chromite-bearing leucogabbro to anorthosite, with minor chalcopyrite, returned values of 575 ppm copper, 710 ppm nickel, 360 ppb palladium, 70 ppb platinum, and 4.04 percent chromium (Sample 226, Table 039.1). Chromite-bearing layers from the overlying Middle Zone contain only weak disseminated sulphide mineralization; grab samples from these layers did not return anomalous PGE values. Significant chromium values obtained from these layers in the Middle Zone include 720 ppm chromium (Sample 224, Table 039.1) and 3.2 percent chromium (Sample 225, Table 039.1). Whittaker (1986) suggested that the potential for economic chromite concentrations in the Crystal Lake Gabbro is low.

Anomalous PGE values were also returned from samples of the Crystal Lake Gabbro taken outside the Great Lakes Nickel Deposit. These include: olivine gabbro (Samples 143, 1123, 1170, and 1214, Table 039.1), coarse-grained to pegmatitic gabbro (Sample 1129, Table 039.1), and chilled gabbro (Sample 190, Table 039.1) from the north limb of the intrusion; and plagioclase-porphyritic gabbro (Sample 198, Table 039.1) and coarse-grained olivine gabbro (Sample 142, Table 039.1) from the south limb of the intrusion.

Future exploration efforts in the Crystal Lake Gabbro should include:

1. A detailed examination of pegmatitic copper and nickel sulphide-bearing gabbros at the base of the intrusion, to assess the potential for high-grade PGE. The copper-nickel mineralization may have resulted from the introduction of sulphur into the magma at the base of the complex by the assimilation of Proterozoic sedimentary rocks. This model has been used to account for the distribution of mineralization at the base of the Duluth Complex in Minnesota (Weiblen 1982).
2. Determination of the distribution of chromite-bearing pods and layers in anorthosites at the base of the Lower Zone and within the Middle Zone.
3. Investigation of the continuity of anomalous PGE values encountered in other areas of the intrusion, such as the junction between the north and south limbs.

The Pine River-Mount Mollie Intrusion also represents an important exploration target for PGEs. Anomalous values were returned from samples of fine- to medium-grained olivine gabbro north of Pine Bay. One grab sample, containing 5 percent chalcopyrite, returned values of 1665 ppm copper, 715 ppm nickel, 245 ppb palladium, and 70 ppb platinum (Sample 83, Table 039.2). A dioritic phase of the

TABLE 039.2. 1987 ASSAY VALUES FOR SAMPLES FROM THE CRYSTAL LAKE AREA

Sample No	Rock Type	Pt (ppb)	Pd (ppb)	Cu (ppm)	Ni (ppm)	Au (ppb)	Ag (ppm)	Pb (ppm)	Zn (ppm)	Cr (ppm)
83	gabbro, Pine R.-Mt. Mollie Int.	70	245	1665	715					
1087	diorite, Pine R.-Mt. Mollie Int.	52	230	2420	685	60				
204	gabbro, Pine R.-Mt. Mollie Int.	190	570	2380	1190	235				
1016	gabbro, south of Pine Bay	80	390	408	220	55			100	
203	diabase, Thompson Island	17	13	3710	2800	6				
1032	diabase, east of Pine Bay	2	35	4900	1690	7				
146	barite-calcite vein, Spar Island			8600	160	35				
1084	calcite-quartz vein, Prince Mine			43	21			1380	2160	
181	calcite-quartz-smithsonite vein Thompson Island			21	8				243	
104	calcite vein, Jarvis Bay			305	53			550		

intrusion located on Victoria Island also returned anomalous PGE values: a grab sample of diorite from a gossan zone assayed 2420 ppm copper, 685 ppm nickel, 230 ppb palladium, 52 ppb platinum, and 60 ppb gold (Sample 1087, Table 039.2). The highest PGE values known from the Pine River-Mount Mollie Intrusion were obtained from samples of coarse-grained gabbro containing chalcopyrite and pyrrhotite, which crops out on Thompson Island. These samples returned values of 2380 ppm copper, 1190 ppm nickel, 570 ppb palladium, 190 ppb platinum, and 235 ppb gold (Sample 204, Table 039.2).

Significant PGE values in the Pine River-Mount Mollie Intrusion are associated with high concentrations of magmatic copper-nickel sulphide mineralization. These sulphide minerals occur in lenses, usually in the coarser grained and more gabbroic parts of the intrusion. Lenses may consist of massive sulphide minerals or may contain disseminated sulphide minerals. In addition, secondary accumulations of sulphide minerals occur along sheared contacts between the diabase dikes and the Pine River-Mount Mollie Intrusion. Exploration efforts should focus on evaluating the continuity of these copper-nickel sulphide occurrences.

Apart from samples from the Pine River-Mount Mollie Intrusion and the Crystal Lake Gabbro, only one anomalous PGE value has been obtained to date. A composite dike, with lithologies similar to those in the Pine River-Mount Mollie Intrusion, crops out on Naomi Island. A grab sample of gabbro containing copper-nickel-zinc sulphide minerals returned values of 408 ppm copper, 220 ppm nickel, 390 ppb palladium, 80 ppb platinum, 55 ppb gold, and 100 ppm zinc (Sample 1016, Table 039.2). Geological mapping has identified similar lithologies on the north shore of Lake Superior, both east and west of Naomi Island.

Mineralization within the Pigeon River diabase dikes is primarily copper-nickel and is associated with magmatic sulphide mineralization. Significant assay values of these elements were obtained from diabase dikes on Thompson Island (Sample 203, Table 039.2) and on the mainland east of Pine Bay (north of Naomi Island) (Sample 1032, Table 039.2). The association among copper-nickel sulphides, PGE values, and mafic rocks in the study area suggests that all sulphide occurrences in diabase should be assayed for PGE content.

Metals of historic importance in the study area include silver, lead, zinc, and barite. Both silver and barite have been mined from large veins (*see* Mineral Exploration). Silver mineralization was found on Spar Island during the present project: a grab sample from a 3.5 m wide zoned calcite-barite vein returned values of 8600 ppm copper, 160 ppm nickel, and 35 ppm silver (Sample 146, Table 039.2).

Samples from outcrops near past-producing mines returned anomalous values of lead and zinc. A chip sample across a quartz-carbonate vein at the Prince Mine returned values of 1380 ppm lead and 2160 ppm zinc (Sample 1084, Table 039.2). Anomalous zinc and lead values were returned from samples from Thompson Island (Sample 181, Table 039.2) and from the west shore of Jarvis Bay (Sample 104, Table 039.2). Most of these calcite-barite veins occur in the north-northwest-trending secondary fracture set, which crosscuts the major linear east-northeast-trending dikes. The largest of these veins occurs on McKellar Island, and it has a significantly high barite content. Assay values of samples obtained by diamond drilling in 1967 range from 28.0 percent $BaSO_4$ to 58.4 percent $BaSO_4$ (Resident Geologist's Files, Ontario Ministry of Northern Development and Mines, Thunder Bay).

OTHER INTRUSIONS

Reconnaissance geological mapping of two other Proterozoic intrusions in the Thunder Bay area, the Moss Lake and St. Ignace Island intrusions, was carried out during the current field season. The Moss Lake intrusion is located on the southeast shore of Black Bay Peninsula and the St. Ignace Island intrusion occurs on the southeast shore of St. Ignace Island, northeast of Thunder Bay in Lake Superior.

Both intrusions are zoned and contain lithologies ranging from gabbroic to granitic. A variety of mafic rocks, including olivine gabbro, gabbronorite, anorthositic gabbro, and pegmatitic gabbro were mapped. Samples of each rock type are presently being assayed for PGEs. Petrographical and geochemical studies of samples from both intrusions will be completed to determine their petrogenesis and metallogenesis. Results will be compared with those from the Keweenawan-age intrusions in the Crystal Lake area.

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040. Lac des Iles (Pd–Pt–Au) Deposit: Geology of the Mineralized Zone, Contact Phenomena and Mafic/Ultramafic Dikes Within the Gabbroic Complex

A.J. Macdonald[1] and G.E. Lawson[2]

[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto

[2]Geological Assistant, Precambrian Geology Section, Ontario Geological Survey, Toronto

INTRODUCTION

Detailed 1:1 000 and 1:100 mapping of the Lac des Iles Pd-Pt-Au (+ Cu-Ni) deposit commenced in 1985 (Macdonald 1985) and was continued in the fall of 1986 and the summer of 1987. This report summarizes the results of the 1986 and 1987 field mapping.

Lac des Iles (LDI) is located within the Thunder Bay Mining District of Northern Ontario, 90 km north-northwest of Thunder Bay, centred upon Latitude 49°10′N and Longitude 89°37′W (Location map).

The LDI gabbroic complex is host to a palladium-platinum-gold-nickel-copper deposit with an estimated reserve of 20.4 million tonnes at 6.17 g/t total platinum group elements (PGE), and a platinum:palladium ratio of 1:7 (The Northern Miner, November 10, 1986). Madeleine Mines Limited of Toronto has announced that the deposit is to be put into production employing open pit mining methods with the capability of milling approximately 2700 tonnes per day (The Northern Miner, July 27, 1987).

Extensive cutting of timber on the gabbroic complex and subsequent scarification during the winter and spring of 1987 has exposed new outcrops in and around mineralized host rocks, permitting modification of previous geological interpretations.

PREVIOUS WORK

Previous geological and exploratory work pertaining to the LDI precious metal deposit has been summarized elsewhere (Macdonald 1985; Sutcliffe and Sweeny 1985; Sutcliffe 1986a) and, for brevity, is not repeated here. In 1987, exploration of the Roby Zone by Madeleine Mines Limited continued, approximately 1 km south of the south shore of Lac des Iles. A number of other properties staked during 1985 and 1986, covering both the mafic and ultramafic portions of the LDI intrusive complex, have seen varying degrees of exploration. The most advanced of these is the Angle Bay property of American Platinum Incorporated of Vancouver, which adjoins the Madeleine Mines Limited property on its eastern flank. In 1986 and 1987, American Platinum Incorporated completed a program of geological mapping, geophysical surveying, 760 m of trenching and subsequent sampling, and is implementing a diamond drilling program (The Northern Miner, August 31, 1987).

A secondary road to the south shore of Lac des Iles was constructed in 1986 by Madeleine Mines Limited connecting to logging roads of the Great Lakes Forest Products Company. In 1987, Madeleine Mines Limited commenced a program to upgrade a winter road to an all-weather road to Lac des Iles from Highway 527 to the east.

GEOLOGY OF THE MINERALIZED LITHOLOGIES

The portion of the gabbroic complex that contains significant PGE mineralization is shown in Figure 040.1. This area was mapped between 1985 and 1987 at a scale of 1:1 000 and selected areas at 1:100 (Macdonald 1985, this report). The Roby Zone is a combination of the E, C and part of the F Zones, as originally given by Pye (1968). In contrast with

LOCATION MAP Scale : 1:1 584 000 or 1 inch to 25 miles.

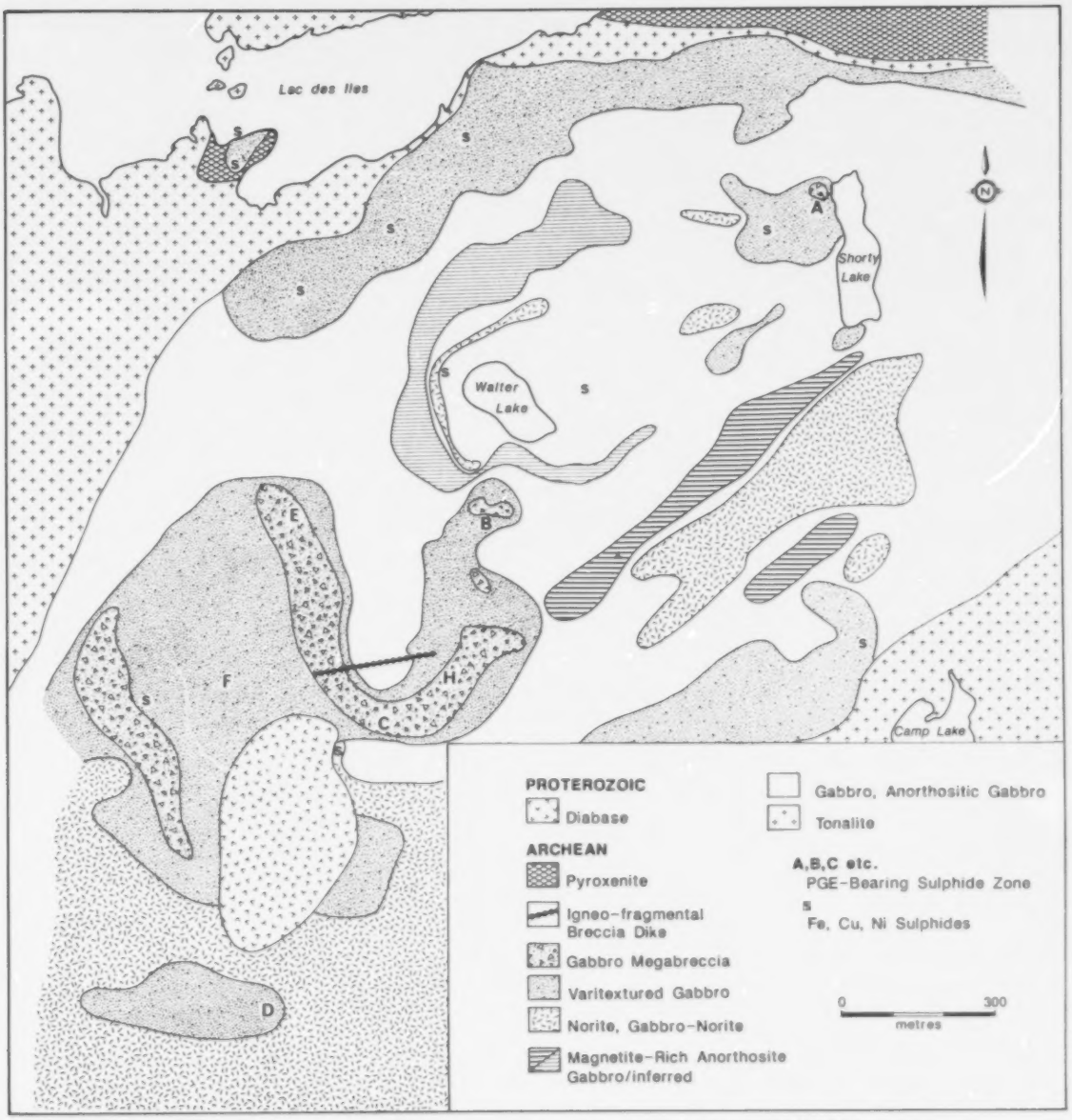

Figure 040.1. *Map of Lac des Iles gabbroic complex, modified from Macdonald (1985).*

monotonous, unmineralized gabbroic rocks, the degree of lithologic complexity is considerable in the vicinity of sulphide-bearing zones, with increases in the amount of:

1. intrusive tonalite
2. anorthosite layers, dikes and pods
3. pegmatoidal gabbro layers and pods, and crosscutting pegmatite dikes
4. heterogenous lithological composition and texture of gabbro (varitextured gabbro), on a hand specimen scale
5. igneo-fragmental breccia dike, and
6. heterolithic breccia zones (gabbro megabreccia).

These features were described initially by Macdonald (1985). The degree of lithological and textural variability is considerable, even on a hand specimen scale, and mapping of individual lithologies is precluded. The area containing these complexities was, therefore, mapped as one unit, termed varitextured gabbro (Figure 040.1). The central portions of varitextured gabbro are dominated locally by zones of igneous breccia (gabbro megabreccia, Figure 040.1). Some observations to supplement those of Macdonald (1985) are presented here.

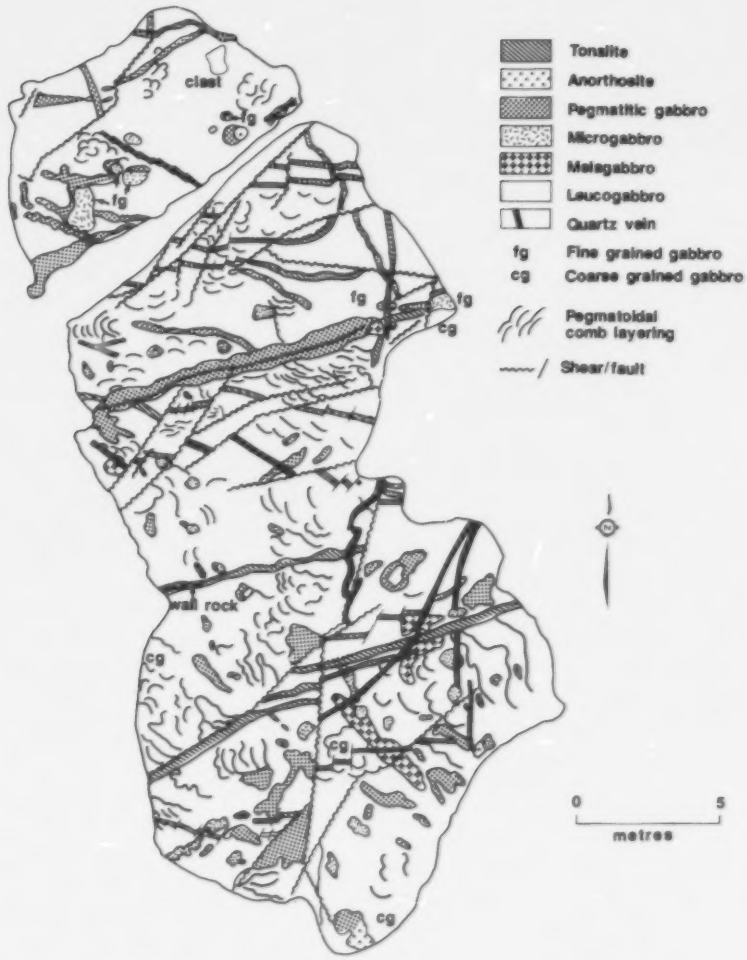

Figure 040.2. *Outcrop Outcrop map of part of the E Zone, Lac des Iles.*

Gabbro in sulphide-bearing zones, and especially in the Roby Zone (Figure 040.1), displays a complex compositional heterogeneity. Figure 040.2 is a map of a portion of the E zone, at the north end of the Roby Zone (Figure 040.1). The map demonstrates some of the complexity encountered in mineralized zones, in contrast to the relatively monotonous, unmineralized gabbro. In this locality, layering dips steeply to the east.

Sulphide-bearing zones are characterized by the development of pegmatoidal gabbro, and by crosscutting pegmatitic gabbro dikes up to a metre in width. Pegmatoidal modal (phase) layering is developed locally and exhibits a cuspate morphology on horizontal surfaces, with the convex side generally to the west and southwest on the outcrop in Figure 040.2, often accompanied by lithologic changes from anorthositic gabbro, to pyroxenite, to pegmatoidal gabbro. Locally, pegmatoidal layers pass with continuity into crosscutting pegmatite dikes, suggesting a relationship between the two.

Individual pegmatoidal layers locally comprise a pyroxenitic base and large, up to 5 cm, crystals of interdigitated pyroxene and plagioclase oriented perpendicular to the pyroxenite layer (Figure 040.3). This type of layering has been termed informally "Willow Lake-type layering" (Poldervaart and Taubeneck 1959), or more generally "comb layering" (Moore and Lockwood 1973). Comb layering is a particularly useful aid in determining the relative direction of the accumulation of crystals in a magma chamber, as is the geometry of the curved combed layers (Moore and Lockwood 1973): the perpendicularly-oriented crystals in Figure 040.3 grew in the magma chamber whose floor or wall consisted at that time of pyroxenite, with the convex side of the layer generally protruding away from the accumulating crystal pile and into the magma from which the crystals formed (*see* Figure 5 *in* Moore and Lockwood 1973).

The pegmatite dikes consist typically of plagioclase and pyroxene crystals, with grain size up to 10 cm. Pyroxene grains are most commonly perpendicular to the pegmatite wall and lithologic contacts may be offset by pegmatites (*see* Photo 2 *in* Macdonald 1985), suggesting that formation of pegmatites was accompanied by at least some open-space filling.

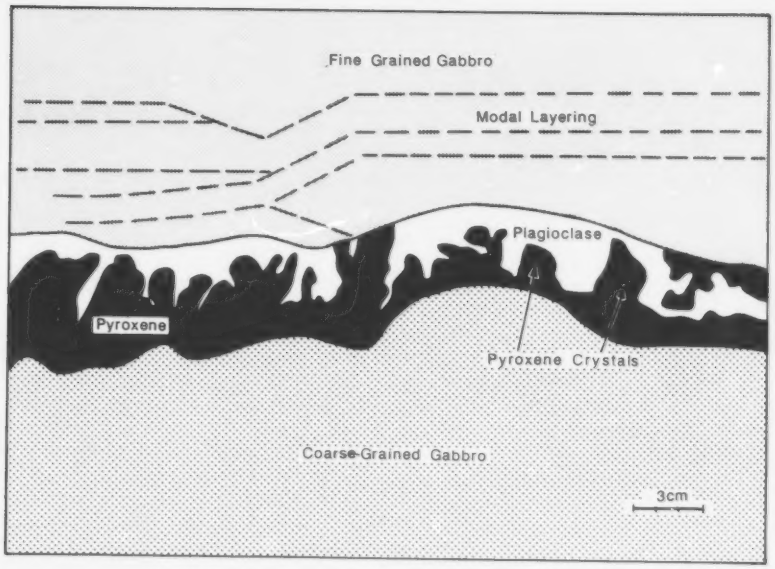

Figure 040.3.
Pegmatoidal comb layer, E zone, northern Roby Zone. Note pyroxenite base and interdigitated pyroxene and plagioclase crystals aligned perpendicularly to layer. Drawn from photograph.

Gabbro pegmatites commonly have pyroxene-rich margins and plagioclase-rich cores, locally quartz-bearing. They sometimes pass laterally into dikes that contain little pyroxene, i.e. an anorthosite. Gabbro pegmatite dikes commonly have a central portion that is quartz-bearing, especially where the dikes are sulphide-rich.

Varitextured gabbro contains at least two types of locally pegmatoidal, sub-spherical pods, up to 50 cm in diameter. The first type consists of anorthosite spherules within a gabbroic matrix (Photo 040.1) and is relatively rare, observed to date in only the A and B Zones (Figure 040.1). At the margins of the anorthosite spherules, individual plagioclase grains are aligned tangentially, parallel to the spherule margin. The second type comprises a pegmatoidal gabbro spherule in a gabbroic matrix (Figure 040.4). Pyroxene grains display radial growth inward from the spherule margin. Spherule centres are commonly anorthositic and locally cored by quartz+tourmaline+sulphides.

Both types of spherule seen at Lac des Iles are similar to examples of orbicular textures described by Leveson (1966). The first type displays some morphological similarity to the "Tennis Ball" lithology described by Lee and Sharpe (1979), in which spherical aggregates of pyroxenite in quartz norite form as a contact phenomenon in the Eastern Bushveld Complex of South Africa. Lee and Sharpe (1979) suggest that aggregation is promoted by introduction to the Bushveld magma of a felsic "bridging" liquid (derived by melting of floor rocks) which preferentially wets suspended solids in the magma, while being immiscible with the suspending liquid. At Lac des Iles, this type of spherule is found near the contact between mafic and felsic rocks (e.g. A Zone, Figure 040.1), which are co-magmatic (Sutcliffe 1986b). It is feasible, therefore, that a similar "bridging liquid" hypothesis may be applicable for spherules such as those in Photo 040.1, with contamination of gabbroic magma by felsic melt at the margin of the Lac des Iles mafic complex.

The second type of spherule (Figure 040.4) is similar to the miarolitic cavities described by Watkinson (1987) in gabbros with alkalic affinities of the Coldwell Complex, on the northeast shore of Lake Superior, Ontario. Pegmatoidal cavities in the eastern margin of the Coldwell Complex are also associated with a PGE deposit in the vicinity of Two Duck Lake.

Previous researchers at Lac des Iles suggested that the Roby Zone was spatially associated with the contact between two gabbros, with the implication that mineralization may be a contact phenomenon (e.g. Dunning 1979). A well-defined pyroxenitic lithology was used during exploration by diamond drilling in the 1970s to outline this contact. This is a critical aspect of the "two gabbro" hypothesis (Dunning 1979). Detailed mapping (1:100) of newly exposed outcrops, however, reveals that the pyroxenite is a dike, intrusive into anorthositic gabbro (Macdonald 1987a). The ultramafic dike mixed chaotically with gabbro at the eastern margin of the E zone (Figure 040.1); cobbles of gabbro are locally contained within pyroxenite (Photo 040.2). As these ultramafic rocks are dikes intruding gabbro, rather than representing a marginal phase of a much larger gabbroic intrusion, the existence of two discrete, intrusive gabbroic bodies must be questioned. No unequivocal intrusive contacts between two gabbro phases have yet been observed in the field.

In exposures revealing clear intrusive relationships between pyroxenite and gabbro (e.g. Photo 040.2), the ultramafic dike cuts pegmatoidal layering within the gabbro. The dike, in turn, is cut by gabbro pegmatite dikes, establishing a relative chronology of the development of pegmatoidal layering, pyroxenite intrusion, and development of the crosscutting pegmatites.

Many of the exposed zones of mineralization are spatially associated with a complex, heterolithic brec-

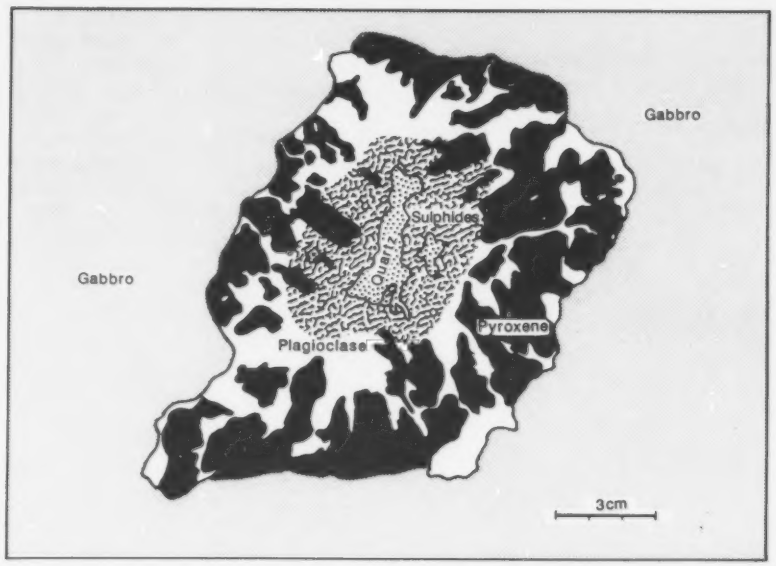

Figure 040.4.
Sulphide-rich miarolitic spherule in E zone, northern Roby Zone. Drawn from photograph.

cia, with clasts up to 5 m in diameter, hence gabbro megabreccia (Macdonald 1985). Some gabbro clasts within a gabbro matrix are coated by "rinds" of either pyroxenite or pegmatoidal gabbro (Figure 040.5), termed orbicular texture (Leveson 1966; Moore and Lockwood 1973), and are found in association with comb layering. The rinds are similar to the constituents of the comb layers.

CONTACTS BETWEEN GABBRO AND FELSIC COUNTRY ROCKS

Three distinct contact relationships are observed between the LDI gabbroic rocks and tonalite gneiss/tonalite country rocks:

1. a sharp, sheared gabbro/tonalite gneiss contact
2. a diffuse, gradational, hybrid contact zone between gabbro and tonalite gneiss, and
3. a gradational hybrid gabbro/tonalite contact.

Two of these contacts are with gneiss and the other with a more equigranular tonalite that Sutcliffe (1986b) has suggested is coeval with mafic intrusion.

Field relationships indicate that the sharp contact between tonalitic gneiss and gabbro is invariably sheared, as indicated by disrupted and juxtaposed, crosscutting mafic and felsic dikes, both of which tend to be fine to medium grained. Fine-grained mafic dikes (doleritic) possess a penetrative foliation parallel to the gabbro/tonalite gneiss contact.

There are two generations of quartz- and plagioclase-bearing felsic dikes that cut across the gabbro/tonalite gneiss contact. The older set comprises thin, discontinous dikes and dikelets that are variably displaced and sheared parallel to the contact. The younger dike set intruded subsequent to deformation related to intrusion. It is possible that the felsic dikes represent a continuum of minor felsic intrusions during and after intrusion of gabbro into

Photo 040.1. *Anorthosite spherules in gabbroic matrix, A Zone. Notebook, 17.5 cm in length, for scale.*

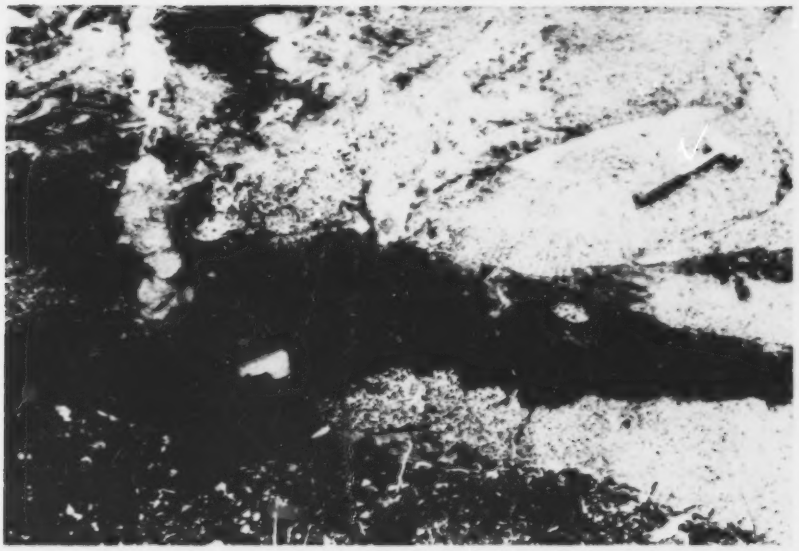

Photo 040.2. *Pyroxenite dike intruding anorthositic gabbro, east side of Roby Zone. Note inclusion of gabbro in pyroxenite. Pyroxenite is cut, in turn, by tonalite dike. Hammer for scale.*

tonalite gneiss. The dikes may be traced along strike into tonalite gneiss, and pass with continuity into tiny, felsic dikelets that fill hairline fractures. It is proposed that the felsic dikelets may be a rheomorphic melt of tonalite gneiss, perhaps in response to heating from the intruding gabbro magma.

The younger felsic dikes are, in turn, cut by fine-grained mafic dikes which also cut the contact, indicating the presence of mafic magma subsequent to the rheomorphically generated, felsic magmas.

Gradational contacts between gabbro and tonalite gneiss occur over as much as 10 m. A medium-grained foliated tonalite gneiss grades into hybrid foliated gabbro gneiss. Contacts between gneissic gabbro and tonalite are irregular and diffuse, giving the outcrop a schlieren texture. Extensive stoping and assimilation of tonalite gneiss by the intruding gabbro occur adjacent to the contact.

The third style of contact relationship occurs between the gabbroic rocks and a coeval tonalitic phase (Sutcliffe 1986b). Contact relationships outlined by Macdonald (1985) indicate that gabbro passes, over 15-20 m, into a quartz-bearing gabbro, which grades gradually into a contaminated tonalite, containing relict pyroxene and, finally, into tonalite.

It is suspected that the three contact relationships described above may be gradational from one to another, depending upon the degrees of:

1. stoping of tonalite gneiss into the intruding gabbro
2. shearing at the gabbro-country rock contact, and
3. melting of tonalite gneiss to form tonalite, with subsequent co-mingling of felsic and mafic magmas, and rheomorphic back-injection of felsic melts into the crystallizing gabbroic melt.

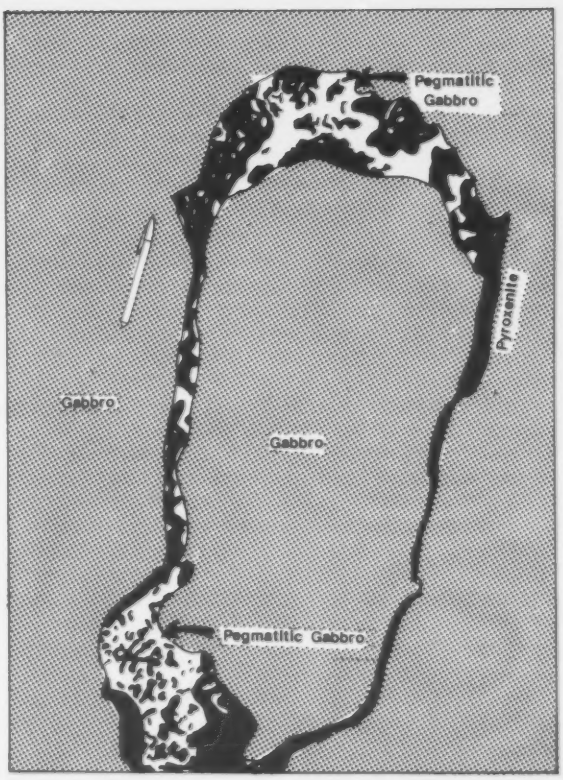

Figure 040.5. *Orbicular textured clast in gabbro megabreccia, E Zone. Pen for scale. Drawn from photograph.*

These observations are of economic significance. Irvine (1975), and Naldrett and Macdonald (1980) have suggested that the addition of silica to a mafic magma may induce sulphide liquation, and subsequent scavenging of PGE from the silicate magma. The field evidence for coexistence of both mafic and felsic magmas in the vicinity of Lac des Iles has been presented by Sutcliffe and Sweeney (1985), Sutcliffe (1986b) and in this study. The tonalite contamination process may indeed account for some of the sulphide mineralization at Lac des Iles, particularly those zones near the contact between gabbro and tonalite (e.g. A and G zones, Figure 040.1), as described by Macdonald (1987a, b). Pye (1968) noted that these zones do not, however, appear to contain the most significant PGE grades, and another factor must be sought to account for elevated grades within the Roby Zone. The effects of tonalite contamination upon the chemistry of the gabbroic host rocks is the subject of ongoing research (e.g. Macdonald *et al.* 1987, in preparation).

MINOR MAFIC/ULTRAMAFIC INTRUSIONS IN THE GABBROIC COMPLEX

Newly exposed outcrops (1987) within the LDI gabbroic complex indicate that minor mafic and ultramafic dikes comprise a significant proportion of the complex, confirming an hypothesis suggested by G.E. Brügmann (Post-doctoral Fellow, Department of Geology, University of Toronto) during reconnaissance mapping in 1986. The dikes range from anorthosite, through gabbro, gabbro norite and norite to pyroxenite (Photo 040.2). Original mineralogy has commonly been destroyed by deuteric alteration: plagioclase to chlorite, sericite and epidote (i.e. saussuritization), clinopyroxene to a fibrous amphibole (i.e. uralitization) and, locally, orthopyroxene to talc. Lithological nomenclature at this stage, therefore, is restricted to descriptive field terminology.

The morphology of intrusive relationships between dikes and host gabbroic rocks can be highly variable. Although modal layering is only rarely developed within gabbroic rocks at Lac des Iles (Macdonald 1985), layering where present may be chaotically disrupted in the vicinity of a mafic/ultramafic dike. In addition, gabbroic material may be disaggregated and mixed with the intruding dike, or back-intruded into the dike itself. These observations collectively suggest that at least some of the mafic/ultramafic dikes have intruded a semi-lithified, mafic crystal pile that still contained magma. A similar proposal has been made by Macdonald (1987a, b) for an ultramafic (websterite) dike in the vicinity of the Roby Zone. These dikes may be of considerable economic significance, as they may contain up to several thousand ppb (Pt+Pd+Au).

Dikes may, in places, be followed in outcrop into bodies concordant with layering in the host gabbro; i.e. dikes pass laterally into sills. In these particular instances, concordant intrusions do not appear to induce significant disruption of the host gabbro, with little disaggregation, mixing, or back-injection as seen in discordant intrusions.

Five of the eight sulphide-bearing zones (Figure 040.1) are in close proximity to gabbro that has been intruded by mafic/ultramafic dikes. These are the B,C,E,F and H Zones (Figure 040.1), of which the Roby Zone is a part. This may be a significant observation, as the mixing of an ultramafic liquid and a magma of anorthositic affinity has been proposed as a process responsible for mineralization in the J-M Reef, Stillwater Complex (Todd *et al.* 1982; Campbell *et al.* 1983; Irvine *et al.* 1983) and in the Merensky Reef, Bushveld Complex (Irvine *et al.* 1983; Irvine and Sharpe 1986; Sharpe *et al.* 1986). There is, however, some discussion as to whether ultramafic liquids pulsed into anorthositic magma, or vice-versa (Campbell *et al.* 1983; Sharpe *et al.* 1986). At Lac des Iles, however, unequivocal field relationships are preserved demonstrating the intrusive relationships between an ultramafic dike and anorthositic gabbro host (Photo 040.2), spatially associated with PGE-rich sulphide zones.

SUMMARY

Contacts between the Lac des Iles gabbroic complex and felsic country rock comprise three end-members:

1. a sharp, sheared contact between gabbro and tonalite gneiss, with rheomorphic, felsic dikes
2. a gradational contact between gabbro and tonalite gneiss, accompanied by stoping and partial assimilation of tonalite gneiss by the intruding gabbro, and
3. a gradational contact between gabbro and equigranular tonalite produced by melting tonalite gneiss.

Mafic and ultramafic dikes intruded the Lac des Iles gabbroic complex during crystallization. The dikes locally disrupted modal layering and mixed with partially consolidated gabbro. Concordant, sill-like intrusions of these rocks can produce features that, with poor outcrop, could be mistaken for modal layering.

IMPLICATIONS FOR EXPLORATION

Although contamination of a mafic magma by felsic material has been proposed as a process that may result in economic concentrations of precious metal-bearing, nickel-copper sulphides at, for example Sudbury, Canada and Noril'sk-Talnakh, the Soviet Union (Naldrett and Macdonald 1980); zones of contamination at Lac des Iles (e.g. the A and G Zones, Figure 040.1), while containing minor copper and nickel sulphide mineralization, do not contain economic concentrations of the precious metals. A number of other zones, however, contain elevated Pd, Pt and Au contents (>1 000 ppb total) and are spatially associated with mafic and ultramafic dikes that are locally mixed with gabbroic host rocks. At least some of these dikes are highly anomalous in precious metals (Macdonald 1987a, b), and may be, in part, responsible for concentration of the metals to economic levels. Interestingly, the zones containing highly elevated precious metals carry the same (Ni+Cu) grades as those zones with low precious metal contents.

Mixing of mafic and ultramafic phases may, therefore, be a significant component of the mineralization process at Lac des Iles; a hypothesis that

has gained acceptance for a number of platinum group element deposits (Macdonald 1987c). A word of caution is necessary, however, for those prospectors and explorationists seeking this type of mineral deposit: the geological relationships described in this study only became clear after several months of extensive overburden removal. The intrusive nature of many mafic and ultramafic phases had not been appreciated in past diamond drilling and geological mapping programs.

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041. Platinum Group Element Mineralization in the Werner-Rex Lakes Area, Northwestern Ontario

G.E. Lawson and P. Zuberec

Geological Assistants, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

This project is a portion of the continuing investigation of platinum group element (PGE) mineralization in Ontario. The project was initiated in 1987 to investigate the source of economically significant platinum (Pt), palladium (Pd), and gold (Au) values returned from samples collected from a mine dump at Werner Lake, and submitted to the Ontario Geological Survey for analysis. Analysis results ranged up to 7210 ppb Pt and Pd (Hailstone and Blackburn 1987).

The Werner-Rex Lakes area is located 80 km northwest of the Town of Kenora, centred upon Latitude 50°30′N and Longitude 95°00′W (Location Map). The area is accessible by float plane from communities in Ontario, such as Kenora, or by a forestry road that connects with Highway 315, north of Lac du Bonnet, Manitoba.

Between 1932 and 1972, the Werner-Rex Lakes area saw sporadic nickel-copper-cobalt-(platinum and palladium) production from sulphide mineralization associated with mafic to ultramafic intrusive plugs within a regionally extensive fault zone. Field mapping in 1987 was performed on an outcrop scale of 1:100 with an emphasis placed upon areas of known mineralization.

REGIONAL GEOLOGY

The Werner-Rex Lakes area is within the English River Subprovince. The dominant lithologies in this portion of the Subprovince include Archean paragneiss, tonalitic and granitic intrusions, and volumetrically minor, but economically important, mafic and ultramafic intrusive rocks. The Sydney Lake Fault Zone (Stone 1981) defines the boundary between the Uchi Subprovince to the north and the English River Subprovince to the south (Stockwell 1964). The Werner Lake-Rex Lakes Fault System (Carlson 1958) is located approximately 20 km southwest of the Sydney Lake Fault Zone.

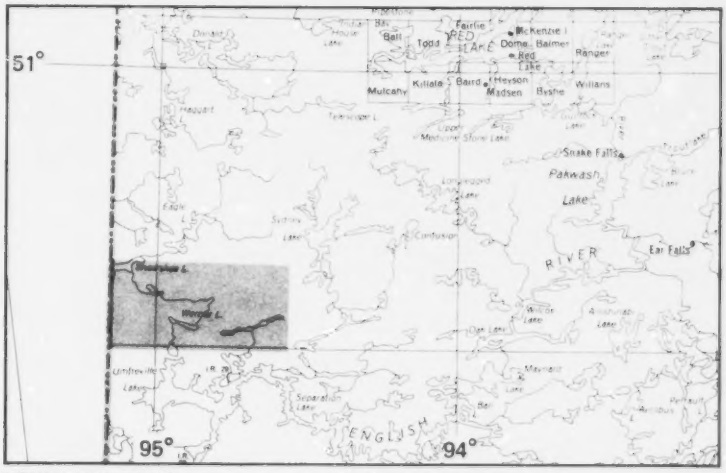
The Werner-Rex Lakes area is characterized by easterly trending belts of supracrustal and plutonic rocks. From oldest to youngest, these rocks are paragneiss, quartz diorite, mafic-ultramafic plugs, granite-granodiorite intrusions, and granitic pegmatites (Carlson 1958). Delineation of geological boundaries is highly subjective, as paragneiss and granitic rocks are interdigitated on all scales.

PREVIOUS EXPLORATION AND MINING

The following information has been compiled from Carlson (1958), Rose (1958), Scoates (1963, 1972) and assessment files in the Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Kenora.

Cobalt was first discovered at the western end of Werner Lake (Figure 041.1) by M. Carlson in 1920. In 1942, H. Byberg and A. Vanderbrink discovered nickel-copper mineralization in peridotite about 3 km east of the cobalt mine, on the southeastern corner of Gordon Lake. A similar discovery was made by prospectors working for Dome Exploration (Canada) Limited near the eastern end of Werner Lake in 1944.

Table 041.1 summarizes exploration, evaluation, and production data for properties in the Werner-Rex Lakes area. Work on the Werner Lake Cobalt Mine in 1929, 1932, and during the period 1940 to 1944 yielded a total production of approximately 63.5 tonnes of cobalt (Carlson 1958). Between 1963 and 1969, approximately 1 325 115 tons (short) (1 202 123 tonnes) of ore were milled, dominantly from the Gordon Lake Mine, which yielded 4223 ounces of platinum (approximately 131 kg) and 32 230 ounces of palladium (approximately 1 tonne); i.e. the ore graded 0.01 g/t Pt, and 0.83 g/t Pd (data in Hailstone and Blackburn 1987).



LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

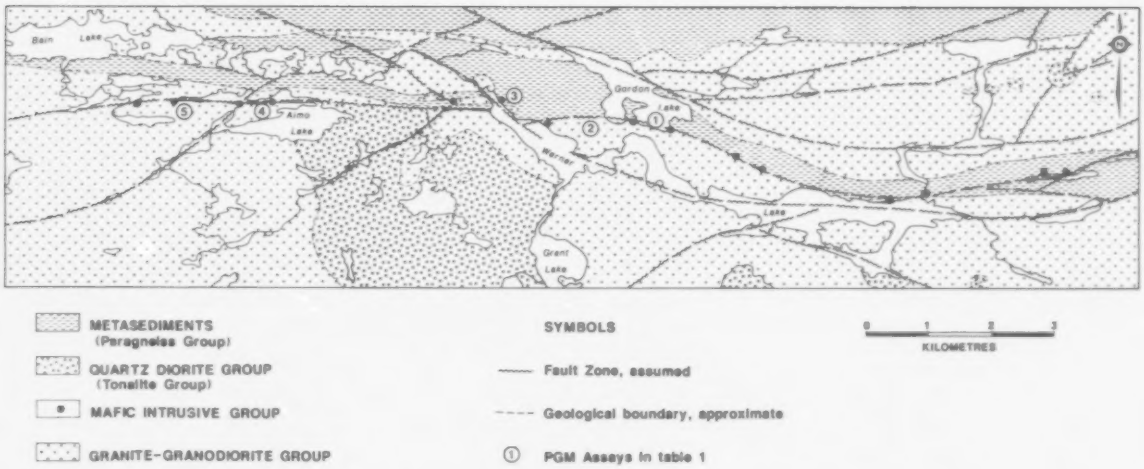


Figure 041.1. *Geology of the Werner-Rex Lakes Area, modified from Carlson (1958).*

LOCAL GEOLOGY

Previous geological studies in the Werner-Rex Lakes area were conducted in 1930 by D.R. Derry and in 1939 by T.L. Tanton (Carlson 1958). Chisholm (1949) gave a brief description of the mineralization. Taylor (1950) described a number of copper-nickel deposits in the Bird River (Manitoba) and Werner-Rex Lakes area. A systematic mapping project was undertaken by Carlson in 1954 and 1955, which resulted in a geological report and maps being published in 1958 (Carlson 1958). In the same year, Rose (1958) described the sulphide mineralization at Gordon Lake. Scoates (1963) studied copper-nickel and platinum group metal distribution at Gordon Lake, and later investigated the petrology and geochemistry of the same deposit (Scoates 1972).

Mineralization in the Werner-Rex Lakes area is confined to an easterly trending fault zone, which is subparallel to the regionally extensive Sydney Lake Fault Zone occurring to the north. These two fault zones may be related. Small, discontinuous plugs and lenses of peridotite and associated mafic rocks have intruded the fault zone (Carlson 1958). Copper-nickel sulphide minerals, with local cobalt and PGE enrichments, are associated with the mafic-ultramafic intrusions. At least 15 discrete intrusions are shown along the Werner Lake-Rex Lakes Fault Zone on Ontario Geological Survey Maps 1957-2 and 1957-3, which accompany Carlson (1958). Several other mafic-ultramafic plugs are also shown on Carlson's maps, in conjugate, northeasterly and northwesterly trending fault sets with no known associated mineralization. Surface exposure is, however, limited, as much of the fault zone is coincident with lakes, drift-filled linear valleys and swamps. Exposed plugs range in size from 4 m^2 to 165 m^2. Diamond-drill logs filed for assessment purposes indicate that the plugs are considerably more extensive in the vertical dimension than in the horizontal (Resident Geologist's Files, Ontario Ministry of Northern Development and Mines, Kenora).

The mafic to ultramafic intrusive plugs comprise peridotite, pyroxenite, hornblendite, and biotite schist. The plugs are fine to medium grained and contain up to 5 percent disseminated sulphide minerals. A thin rind of biotite schist typically surrounds each plug (Figure 041.2). The random orientation of biotite grains indicates that biotite formed subsequent to dynamic metamorphism experienced by paragneiss in the area, and that intrusion of the plugs was passive. Traverses across mineralized plugs indicate that intrusion produced little visible effect upon surrounding country rock.

ECONOMIC GEOLOGY

Table 041.2 lists published assays of samples from the Werner-Rex Lakes area. Locations for these samples are given on Figure 041.1.

Metallic minerals in the Werner-Rex Lakes mineralization include chalcopyrite, pyrrhotite, pyrite, and magnetite, which are present in pods, lenses, and disseminations. The Werner Lake Cobalt Mine is also characterized by the presence of cobaltite. There is no record of identified platinum group minerals in the Werner-Rex Lakes area. The sulphide minerals generally occur as disseminated blebs ranging from 0.5 to 5 percent of the host rock. Small, localized bands of massive-sulphide minerals (3 to 6 cm wide) are also present and may represent a remobilized fraction of the disseminated sulphide minerals. The massive-sulphide minerals may also form the matrix to a breccia ore, which contains clasts of country rock (Photo 041.1). The breccia ore appears superficially similar in hand specimen to "inclusion massive sulphide" from the Sudbury nickel-copper precious-metal ores (Naldrett 1984). Magnetite is also present, disseminated as small blebs throughout the plugs.

In most cases, mineralization is restricted to the plugs, although underground mapping by Rose (1958) indicated that sulphide minerals had been remobilized into the surrounding country rock by late, cross-scutting, pegmatite dikes.

TABLE 041.1. PREVIOUS EXPLORATION AND MINING

Year	Company/Prospector	Activities	Outcome/Results
1920	M. Carlson	Prospecting	Discovery of Cobalt in the Werner Lakes Area
1928-29	Kenora Prospecting Mining Ltd.	Restaking of land previously staked by M. Carslon	1929,32 and 1940-44 extraction of 63.5 tonnes of cobalt with average grade of 2% Co; 0.75% Cu and <0.1% Ni
1942	H. Byberg and A. Vanderbink	Prospecting, trenching, diamond drilling	Discovery of Cu-Ni mineralization in the Gordon Lake Area
1940-44	Noranda Mines Limited	Trenching, diamond drilling	Claims lapsed
1945(?)	Eastern Mining and Smelting Co., Ltd. (EMSCL)	Restaking of ground previously owned by Noranda	Outlined G Zone - 542,000 tons of peridotite containing 0.42% Ni, 0.68% Cu, 0.07 g/t PGE Outlined B Zone - 786,000 tons averaging 1.15% Ni, 0.30% Cu, 4.1 g/t PGE
1948	Rexora Mining Corp. Ltd.	Acquisiton of property from EMSCL and optioned to Falconbridge who conducted geophysical surveys and diamond drilling	
1948-1949	Inco Ltd; Frederick Mining & Development Ltd.: Radio Active Minerals Ltd; Rexora Mining Corp. Ltd.; Toburn Gold Mines Ltd.	Geological and geophysical surveys	
1952	Quebec Nickel Corporation Limited	Acquisiton of property previously owned by Noranda Rexora, Falconbridge and INCO -diamond drilling -underground exploration and development	
1953	C., Alcock Norpax Oils and Mines Ltd. - Optioned to Selco Exploration Company Limited	-diamond drilling and underground exploration and development	
1955-1967	Consolidated Faraday Ltd.	Corporate restructuring of Quebec Nickel Corp. Ltd.	Bulk of production at Gordon Lake between 1962-1972: 1.2 MT 0.01 g/t Pt, 0.83 g/t Pd

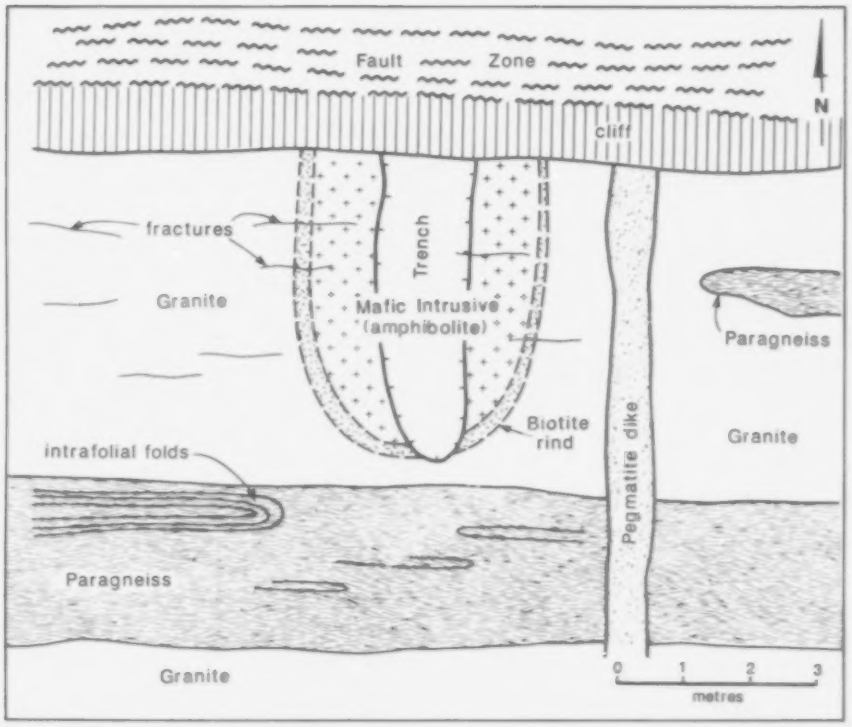


Figure 041.2. *Geological sketch map of mineralized mafic/ultramafic plug, Werner Lake.*

TABLE 041.2. ASSAYS, WERNER-REX LAKE AREA.

Location on Fig.1	Sample	Cu(%)	Ni(%)	Co(%)	Pt(g/t)	Pd(g/t)	Rh(g/t)	Source
1	B-Breccia 300′ level	0.03	6.4	31.9	0.9	5.6	1.4	2
1	B-Breccia 450′ level	0.08	3.35	0.09	1.0	7.0	1.6	2
1	Dissd. 300′ level	1.6	0.85	0.03	0.1	1.8	0.2	2
2	DDH Avg. 45′(13.7m)	1.39	2.58		1.7	3.1		1
3	Surface Grab	1.79	1.12		0.3	2.4		1
4	Surface Grab	0.44	1.32		0.3	0.3		3
5	Surface Grab(20′)	0.16	0.18		0.7	0.7		3

References: 1: Chisholm (1949)
2: Scoates (1963)
3: Assessment Files, Kenora MNDM

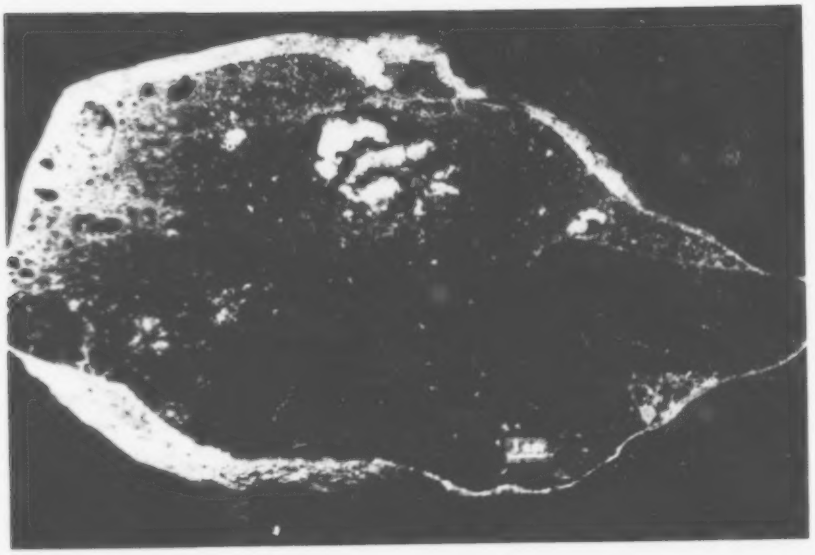


Photo 041.1. *Breccia sulphide ore, Gordon Lake Mine dump.*

SUMMARY

The Werner-Rex Lakes area is host to several sulphide-mineral-bearing, mafic to ultramafic plugs which have intruded a regionally extensive, easterly trending fault zone. Similar plugs are present on conjugate, northeast- and northwest-trending faults, which may warrant further exploration.

The sulphide-mineral-bearing plugs locally contain economically significant platinum group element mineralization. Field mapping indicates that the sulphide minerals are most commonly restricted to being within the mafic-ultramafic plugs.

RECOMMENDATIONS FOR EXPLORATION

Carlson (1958, p.21) notes that most of the showings were discovered by prospectors working with "an idea and a grub hoe". As many of the ultramafic rocks have been subjected to serpentinization, forming accessory magnetite, the rocks are amenable to detection by geophysical means (magnetic-susceptibility survey).

Mineralization of this style lends itself to modern geophysical-prospecting techniques to localize the mafic-ultramafic intrusions spatially associated with locally PGE-bearing sulphide minerals. Magnetic-susceptibility surveys can indicate the presence of altered ultramafic bodies. Coincident induced polarization or electromagnetic anomalies may indicate where sulphide minerals are associated with the mafic-ultramafic bodies. In areas of overburden, the geophysical anomalies will require testing by diamond drilling.

ACKNOWLEDGMENTS

We are grateful for much assistance from the Kenora District Office of the Ministry of Northern Development and Mines, especially G. Vogg (Geological Assistant, Ministry of Northern Development and Mines) and the Resident Geologist, C.E. Blackburn. Jon Scoates (Geologist, Geological Survey of Canada) is thanked for an introduction to the geology of the area. We also greatly appreciate the kindness and hospitality of J. Bowen, D. Bowen, and R. Heinrich from Selkirk, Manitoba.

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042. Platinum Group Element Studies: The Abitibi Greenstone Belt

D.J. Good

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto

INTRODUCTION

This study was initiated to examine the potential for the discovery of platinum group element (PGE) mineralization in the Abitibi Greenstone Belt, to meet the growing interest of the exploration industry in PGE mineralization. Occurrences of PGE's were known from the Abitibi Greenstone Belt, but knowledge of their setting, and of the potential of the belt to host economic concentrations of the PGE's was, at best, limited. It was apparent that an understanding of the known PGE mineralization in the Abitibi Greenstone Belt would be an essential first step in assessing its potential for more PGE mineralization.

The association between PGE's and nickel-sulphide mineralization in mafic and ultramafic rocks is well documented (Naldrett and Cabri 1976; Naldrett *et al.* 1979). This knowledge suggested two paths of investigation for the first stage of the study:

1. to examine thoroughly the previous producers of PGE's in the Abitibi Greenstone Belt, and
2. to expand the database for PGE concentrations in the Belt by examining selected layered, tholeiitic intrusions and komatiitic rocks

Both avenues of investigation were pursued during the 1987 field season. A detailed study of the Kanichee Deposit near the Village of Temagami, from which PGE's were recovered as a by-product, was begun (*see* D.J. Good, article 043, this volume). This report presents the preliminary results of field investigations of four mafic-ultramafic intrusive bodies in

LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

the Abitibi Greenstone Belt. As well, several previously reported nickel-copper or copper-sulphide-mineral showings, related to mafic intrusions or ultramafic rocks in the Abitibi Belt, were visited and sampled for the purpose of analysis of their PGE content.

Previous production of platinum group metals in the Abitibi Greenstone Belt occurred between 1973 and 1976 when they were recovered as a by-product from the processing of nickel-copper sulphide-mineral ores from the Kanichee Mine, and from the Langmuir Mine located about 32 km southeast of the City of Timmins.

The characteristics of PGE mineralization at the Kanichee Deposit are currently being investigated by the author (this volume), and are not considered further in this report. The Langmuir Mine, which was examined by Green (1978) and Green and Naldrett (1981), is one of several nickel-sulphide-mineral bodies within 70 km of the City of Timmins that are associated with komatiitic flows. Coad (1979) presents a summary of these deposits, and the precious-metal contents of four other deposits (Hart, Texmont, Alexo, and Dundonald) were described by Barnes *et al.* (1981) and Barnes (1983). These komatiite-associated sulphide-mineral deposits are well described in the literature; consequently, no field work was carried out on them during the initial stage of this study.

DESCRIPTIONS OF STUDY AREAS

1. INCO Limited Property, Strathy Township

The INCO Limited Property is located 4.5 km north of the Village of Temagami in Strathy Township. It consists of four contiguous, patented claims which have been held by INCO Limited since 1902. The entire property is accessible along cut lines, spaced at 200-foot intervals, which intersect both the Kanichee Mine Road and the Trans-Canada Pipeline.

Of main economic interest on the property are the sulphide minerals which occur within both a fragmental ultramafic unit and a layered gabbroic sill, the Net Lake Intrusion. This mineralization is in part exposed on five large outcrops. These large outcrops were cleared of overburden by INCO Limited during 1984 and 1985, and were subsequently mapped in detail for this study. Certain aspects of this project will continue in cooperation with A.J. Fyon (Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto) who is working on a regional metallogenetic study (Fyon and O'Donnell, article 029,this volume).

The property was mapped by Moorhouse (1942), Bennett and Innes (1971), and Fyon and Crocket (1986), as part of geological mapping projects in Strathy Township.

The Archean metavolcanic-metasedimentary stratigraphy in Strathy Township strikes approximately northeasterly, faces southwards, and consists of two mafic to felsic volcanic cycles (Bennett 1978). These cycles are equivalent to the Lower Volcanic Group and Middle Volcanic Group as described by Fyon and O'Donnell (article 029, this volume). The INCO Property is partially underlain by rocks of the Lower Metasedimentary Sequence of the Middle Volcanic Group. The local stratigraphy is discussed by Fyon and O'Donnell (article 029, this volume).

The ultramafic fragmental unit and layered gabbroic sill (Net Lake Intrusion) which were examined for this study are in contact with each other and strike northeasterly through the property. To the southwest, the ultramafic fragmental unit overlies a unit of iron formation; both units can be traced for almost 10 km along strike. On the INCO Property, the layered gabbroic sill has intruded along the lower contact of the ultramafic fragmental unit, apparently displacing the iron formation.

The Net Lake Intrusion is approximately 200 m thick and 4 km long (Fyon and O'Donnell, article 029, this volume). It comprises a thin, coarse-grained pyroxenite base which grades rapidly to a medium-grained gabbro. This medium-grained gabbro is overlain by a medium- to coarse-grained anorthositic gabbro.

The ultramafic fragmental unit consists of both pyroxenite and olivine peridotite zones, but the relationship between them is obscured by numerous mesoscopic faults and gossany-weathered surfaces. Both the pyroxenite and the olivine peridotite are locally fragmental. The fragments are poorly sorted, angular, lapilli sized, monolithic, and ultramafic in composition. The matrix is similarly ultramafic in composition. Textures within an olivine peridotite unit suggest the fragmental units are a result of flow brecciation. However, at the Mayfair Property, located approximately 3 km southeast along strike, Fyon and Crocket (1986) observed distinct layering, accompanied by size grading, in a pyroxenitic unit, and postulated that the layering might be bedding. The possibility exists, therefore, that the fragmental nature is a product of either flow brecciation or resedimentation, and that both processes may have occurred here.

Sulphide minerals occur in four different setings within both the layered gabbroic sill and ultramafic fragmental unit. The following is a summary of these four settings (modified after Fyon and Crocket 1986):

1. disseminated pyrrhotite and exsolved pentlandite and chalcopyrite occur in the pyroxenite layer at the base of the gabbroic sill
2. local, disseminated to net-textured pyrite, pyrrhotite, and pentlandite occur within the ultramafic fragmental units
3. stringer-emplaced sulphide minerals, consisting of pyrite, chalcopyrite, and minor pentlandite and galena, are associated with quartz veins in northeast-trending shear zones that cut the gabbroic sill and ultramafic units
4. small, discontinuous, randomly oriented, stringer-emplaced sulphide minerals, essentially pyrite, pyrrhotite, and chalcopyrite, occur within the ultramafic fragmental unit

Research on the INCO Property will continue in coordination with A.J. Fyon. Samples selected during field mapping will be analyzed for PGE's, and major and trace elements. This part of the PGE study will assess the PGE concentrations in each of the four

mineralization settings, and interpret the petrogenesis of the ultramafic fragmental unit.

2. THE CHARLTON SILL

The Charlton Sill is located in Dack Township, 41 km south of the Town of Kirkland Lake. The sill is well exposed along the Engelhart River within the Town of Charlton. During the 1987 field season, this exposure was mapped at a scale of approximately 1:300 and sampled for a petrologic and geochemical (including PGE) study.

Dack Township was geologically mapped by Moorhouse (1941) and Johns (1986). The petrology of the sill (Charlton Ultramafic Intrusion) was described by Johns (1986).

Dack Township is underlain by an east-northeast-striking, south-facing, homoclinal sequence of tholeiitic and minor komatiitic flows. This sequence was subdivided into the older Wabewawa Group and the Catherine Group by Jensen (1978). The Round Lake Batholith intrudes the base of the Wabewawa Group, and the Charlton Sill intrudes the Wabewawa Group close to its contact with the Catherine Group.

The only exposure of the Charlton Sill occurs along the edge of the Engelhart River. However, the sill was interpreted by Johns (1986), using Geological Survey of Canada Aeromagnetic Maps 1506G and 1494G (Geological Survey of Canada 1965a and 1965b, respectively), to be 3 km long and 400 m thick. It strikes east-northeasterly, and has a vertical dip.

Layering in the Charlton Sill is complex . In general, two partial cycles, at least 65 m thick, of peridotite to gabbronorite are exposed. The peridotite unit consists of interlayered, medium- to coarse-grained clinopyroxenite and fine- to medium-grained olivine peridotite. A very coarse grained pegmatite intrudes the pyroxenite under the westernmost bridge on the Charlton Road. The pegmatite consists essentially of 1 to 8 cm long orthopyroxene crystals, with minor magnetite, hornblende, biotite, and chlorite. The gabbronorite unit consists of interlayered pyroxenite, gabbronorite, and gabbro. Thin layers near the top of the upper cycle exhibit rhythmic layering (Johns 1986, p.37, photo 2). A petrologic description for these rocks is available in Johns (1986).

Disseminated sulphide mineralization occurs in the gabbro of the lower cycle. The mineralization consists of fine- to medium-grained blebs of pyrite and chalcopyrite.

3. MUSKASENDA LAKE INTRUSION

The Muskasenda Lake Intrusion, located about 40 km south of the City of Timmins, strikes approximately northwards for 20 km from Beemer Township, through English and Bartlett Townships, to McArthur Township.

A small area, roughly 425 m by 425 m square occurring at the base of the intrusion was mapped at a scale of 1:1200 during the 1987 field season. Seven samples, representative of mappable units, were selected for petrologic, geochemical, and PGE analysis.

Portions of the intrusion were previously investigated during regional mapping by Pyke (1978a) and Bright (1984). A composite map of the Peterlong Lake area, which includes the entire intrusion, was produced by Pyke (1978b).

Pyke (1978b) recognized two cycles of volcanism in the Peterlong Lake area. The cycles consist of a lower unit of ultramafic flows, a middle unit of mafic metavolcanic flows and an upper unit of intermediate to felsic metavolcanics. The Muskasenda Lake Intrusion was emplaced near the contact between the middle and upper units of the lower cycle.

The intrusion consists mainly of medium-grained, melanocratic gabbro, and subordinate anorthositic gabbro, quartz gabbro, and pyroxenite (Pyke 1978a). Pyke identified only three outcrops of pyroxenite along one short interval of the basal contact. This area where pyroxenite occurs was examined in detail in 1987.

The base of the intrusion is in contact with pillowed basalt. Five igneous layers, averaging 40 m in thickness, form mappable units which strike north-northeasterly, parallel to the basal contact. These units are overlain by the very regular mesocratic gabbro.

The three basal layers are pyroxenite, but they exhibit differences in textures that may be indicative of compositional changes. Textural differences include changes in grain size and the habit of pyroxene pseudomorphs. In general, the pyroxenite layers consist of coarse to very coarse grained (up to 2 cm), tabular crystals of amphibole which are pseudomorphs of pyroxene. One thin section of pyroxenite examined by Pyke (1978a) contained 85 percent, pale green, actinolitic hornblende; 12 percent chlorite; and 3 percent leucoxene. The two upper pyroxenite layers consist of spotted gabbro, which is a fine- to medium-grained melagabbro that contains up to 25 percent, evenly distributed, anhedral plagioclase. Anorthositic gabbro is medium grained and contains up to 15 percent, anhedral amphibole.

4. THE MANN TOWNSHIP MAFIC-ULTRAMAFIC COMPLEX

A portion of the large mafic-ultramafic complex in Mann Township, located approximately 60 km north-northeast of the City of Timmins, was also examined during the 1987 field season. The complex was included in the study because palladium (Pd) mineralization within it is indicated on the Timmins-Kirkland Lake Geological Compilation Series map (Pyke *et al.* 1973).

The portion of the complex studied is located along the Frederick House River, northwest of Pickerel Lake. A clean outcrop approximately 80 m by 40 m in dimension, and exposed along the river under the bridge of a forest-access road intersecting Highway 11 (about 27 km south of Cochrane) was mapped at a scale of 1:250. The petrology and geochemistry (including PGE) of seven samples collected from this outcrop will be the subject of further study.

Examination of other outcrops of the intrusive complex, along the river, as well as of diamond-drill core taken from the area and stored at the Drill Core Library, Ontario Ministry of Northern Development and Mines, Timmins, complemented the detailed investigation of the bridge outcrop.

The area was mapped by Satterly (1959) and Bright and Hunt (1972). A compilation map of geophysical data and a summary of the exploration to 1979 was produced by Hunt and Richard (1980). Mann Township was included in a gravity survey of the Timmins-Matheson area (Middleton 1976).

Previous exploration in the area has focused on nickel/copper mineralization. Between 1947 and 1949, P.B. Zevely (prospector) conducted geological mapping and geophysical surveys and diamond-drilled 17 holes on his claims along the Frederick House River. Pyrrhotite, pyrite, chalcopyrite, pentlandite, and chromite, in subeconomic quantities, were indicated to occur in the diamond-drill core (Assessment Files Research Office, Ontario Geological Survey, Toronto). Noranda Exploration Company Limited conducted ground-magnetometer surveys which indicated four weakly conducting anomalies (Assessment Files Research Office, Ontario Geological Survey, Toronto).

The ultramafic-mafic complex is near the western end of a belt of layered mafic and ultramafic sills and ultramafic bodies which extend along strike to the east-southeast for over 75 km into Munro Township (R. Johnstone, Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto, personal communication, 1987). The ultramafic-mafic rocks are interlayered with minor sediments and intermediate metavolcanic rocks.

The outcrop mapped in detail consists of 2 to 20 m thick, peridotite/pyroxenite sills which strike northwesterly, dip moderately to the east and face eastward. Along the eastern and western edges of the outcrop, peridotite bodies were emplaced along north-trending faults that are visible on the outcrop. On the eastern shore of the river, a north-trending gabbroic body is separated from the peridotite by a visible fault.

At least six sills were identified on the outcrop. A generalized section of the sills consists of a fine- to medium-grained peridotite base, overlain by medium-grained pyroxenite which contains fragments near the top of the sill. The basal contact is sharp. The contact between the peridotite and pyroxenite within the sill is gradational. Neither spinifex nor polysutured textures were observed either at the top of the sill or elsewhere in the outcrop. Fragments at the top of the pyroxenite are subrounded, matrix-supported clasts of pyroxenite and minor peridotite, similar in composition to units within the sill.

No sulphide minerals were seen on the outcrop. To date, no justification for the palladium (Pd) mineralization indicated on the compilation map (Pyke *et al.* 1973) has been found in either the assessment files or in the field. Seven samples of pyrrhotite-rich drill core from the P.B. Zevely Property, where the palladium mineralization is indicated, were submitted for analysis, but the highest value returned was 17 ppb Pd.

ACKNOWLEDGMENTS

B. Sifrer provided assistance in the field and conducted some independent mapping. Thanks are extended to R.J. Perry (Project Geologist) and B. Bell (Senior Geologist) INCO Limited, Sudbury, for permission to examine the INCO Property.

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043. Platinum Group Element Studies: The Kanichee Deposit

D.J. Good

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Kanichee ultramafic/mafic layered intrusion is located 6.5 km northeast of the Town of Temagami in Strathy Township, northeastern Ontario. At the northern end or base of the intrusion, significant nickel-copper-precious metal mineralization is localized within vein sulphide mineralization. Relationships between primary magmatic compositions of the intrusion and the remobilized vein sulphide compositions, with respect to platinum group element (PGE) concentrations, are the focus of this study.

For the study, samples selected from favourable locations, identified by geological mapping, will be analyzed for PGE. Initially, 27 samples will be analyzed. New outcrop along the southwestern edge of the open pit, exposed by overburden removal in early July, was mapped at a scale of 1:250 (Figure 043.1) and the rest of the intrusion was mapped at a scale of approximately 1:4800 (Figure 043.2).

Some aspects of this project will continue in coordination with A.J. Fyon (Geologist, Ontario Geological Survey, Toronto) and R.S. James, (Professor, Laurentian University, Sudbury), who are currently working in the area.

PREVIOUS WORK

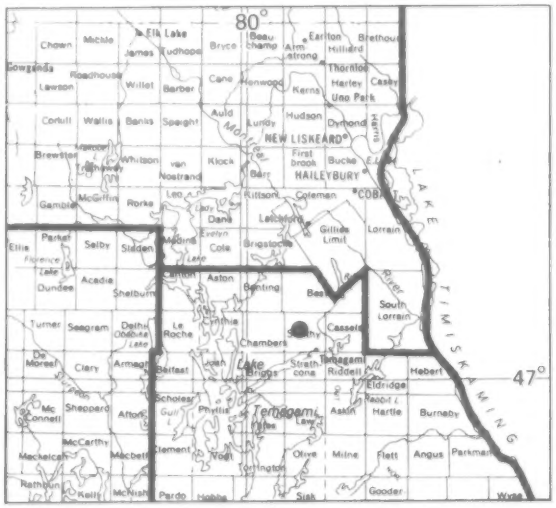
The Kanichee (Ajax) Intrusion has been the focus of several studies. It was examined during a regional mapping project conducted by Moorhouse (1946), Bennett and Innes (1971), and Bennett (1978) described some petrology of the intrusion. A mineralogical study of two hand specimens of sulphide ore was conducted by Cabri and Laflamme (1974). The petrology and geochemistry of the intrusion were described by Hawke (1982) and James and Hawke (1984).

MINE PRODUCTION

The deposit was mined in 1936 by Cuniptau Mines Limited (Thomson *et al.* 1957) and, between 1974 and February 1976, by Ajax Minerals Limited (Canadian Minerals Yearbook 1974, 1975, 1976).

Cuniptau Mines Limited produced a total of 45 t (99 284 pounds) of copper, 29.7 t (65 434 pounds) of nickel, 1151 g (37.0 ounces) of gold, 28 304 g (910 ounces) of silver, 2572 g (82.7 ounces) of platinum, and 6106 g (196.3 ounces) of palladium from 3010 t (3318 tons) milled.

Ajax Minerals Limited excavated an open pit to a depth of 35 m and produced a total of 1404 t of copper and 617 t of nickel from 251 437 t of ore (Canadian Minerals Yearbook 1976). The average grade was 0.72% copper and 0.50% nickel. Documentation of precious metal production by Ajax Minerals Limited is unavailable, but the average assays of mill concentrate for 1974 and 1975 contained 11 140 ppb Pd, 2023 ppb Pt, 2049 ppb Au, 2.84% Ni, and 9.56% Cu (Naldrett and Cabri 1976, p.1145).



LOCATION MAP

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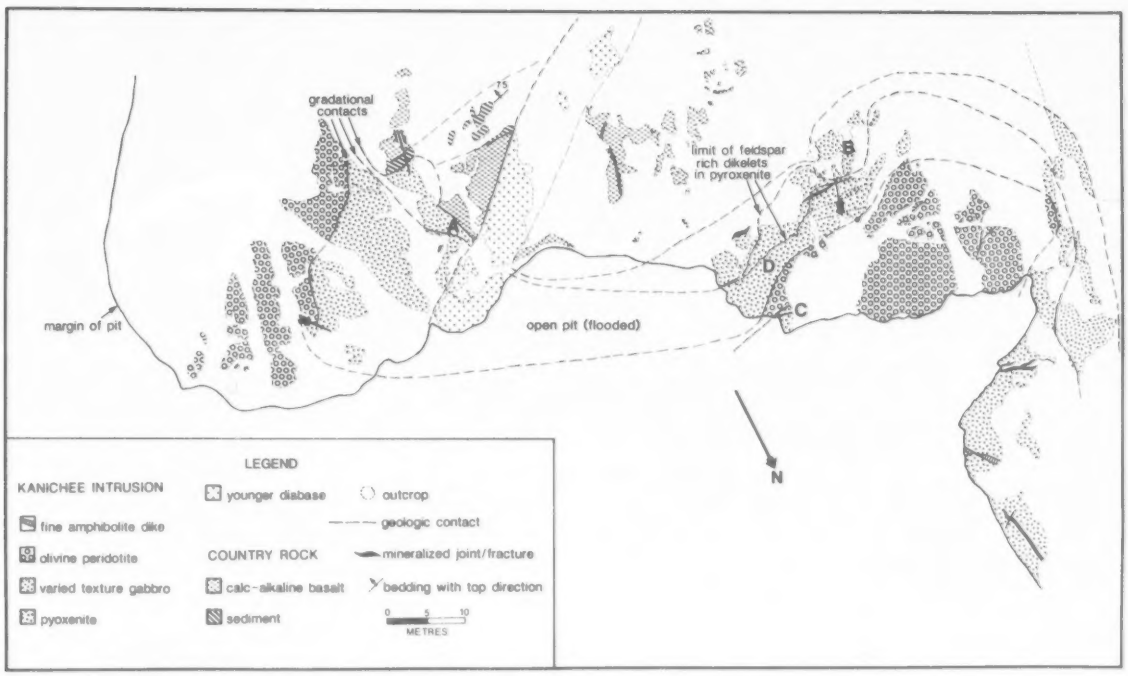

Figure 043.1. *Geological map of outcrop around the southern edge of the open pit.*

REGIONAL GEOLOGY

The Archean metavolcanic-metasedimentary stratigraphy in Strathy Township strikes northeast, faces south, and consists of two mafic to felsic cycles (Bennett 1978). These cycles are equivalent to the Lower Volcanic Group and Middle Volcanic Group described by Fyon and O'Donnell (Article 029, this volume). The Kanichee ultramafic/mafic body intruded interlayered conglomerate and calc-alkalic metavolcanic flows and pyroclastics near the top of the Lower Volcanic Group (Fyon and O'Donnell, Article 029, this volume).

LOCAL GEOLOGY

In plan view, the intrusion is approximately 1070 m thick and 760 m wide. Igneous layers in the intrusion face southeast, strike approximately northeast, and dip steeply south. The intrusive body as a whole plunges to the southeast (D. James, Professor, Laurentian University, Sudbury, personal communication, 1987).

The intrusion is dominantly ultramafic, with minor gabbroic components. Hawke (1982) outlined five igneous cycles, based on the geochemical and mineralogical trends of 44 samples collected on two traverses across the intrusion, and 17 samples collected in the vicinity of the open pit. Of the five cycles proposed by Hawke (1982), only the pyroxenite and gabbro at the top of cycle 5 form mappable units. Cryptic layering in cycles 1 to 4 of Hawke (1982) consist of olivine peridotite or dunite bases which grade upward to peridotite or pyroxenite tops.

A geological map (Figure 043.1) of the recently exposed outcrop around the open pit, compiled during the 1987 field season, indicates conformable layering of olivine peridotite and pyroxenite. However, additional mapping over the rest of the intrusion (Figure 043.2) has outlined several lenses or pods, from less than 1 m to greater than 15 m in size, of clinopyroxenite within the peridotite. The clinopyroxenite bodies have gradational contacts with the enclosing peridotite. Similarly, outcrops of peridotite are found within the clinopyroxenite layer of cycle 5. It is evident, therefore, that the intrusion is more complex than the five outlined cycles suggest.

The ultramafic rocks are dominated by olivine peridotite, but range in composition from dunite to clinopyroxenite. Pseudomorphs of olivine and local minor orthopyroxene are recognizable in outcrop and a significant amount of clinopyroxene is apparently fresh. Olivine grains are subhedral and range in size from less than 1 mm to 3 mm, but are most commonly approximately 1 mm. Clinopyroxene occurs as short, prismatic, subhedral crystals that are usually coarser grained than olivine and range from 1 to 3 mm in size. Orthopyroxene forms prismatic crystals up to 5 mm long. Alteration products are primarily serpentine, magnetite, tremolite, hornblende, and talc.

At point A on Figure 043.1, the contact between the gabbro and the calc-alkalic basalt country rock is well exposed. Approaching the contact, the grain size of the gabbro decreases from medium to fine, and,

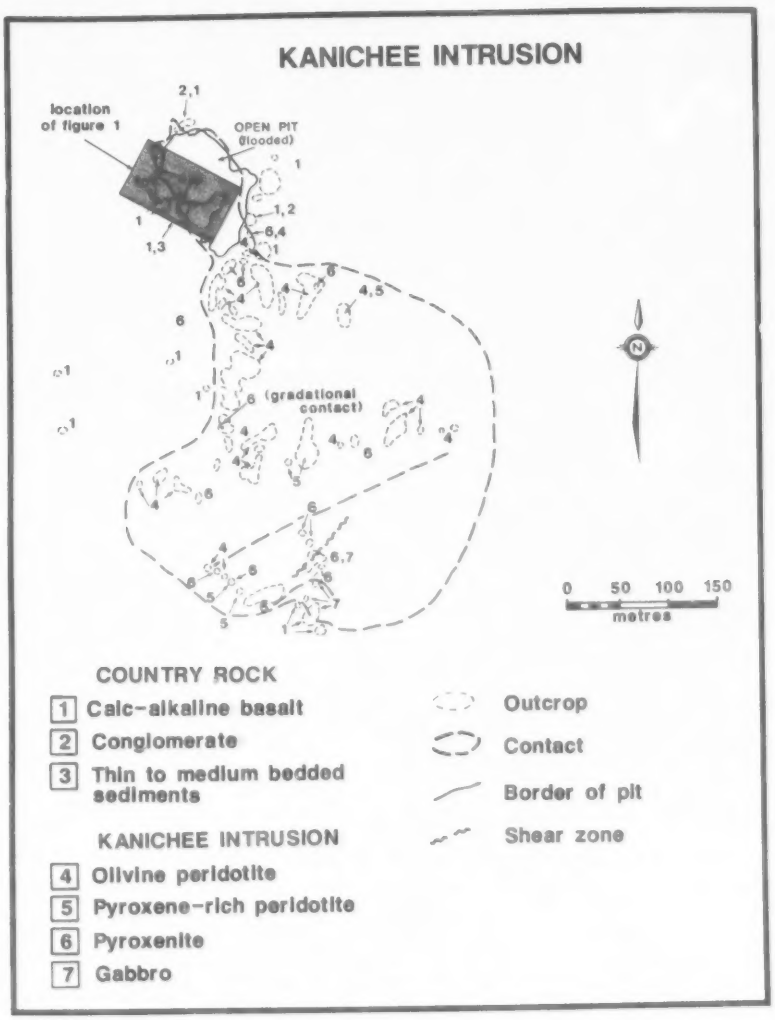

Figure 043.2. Geological map of the Kanichee Intrusion.

compositionally, the gabbro becomes more leucocratic, over approximately 1 m. Textures within 2 to 5 cm of the contact suggest partial assimilation of the calc-alkalic basalt. The contact is gradational and irregular. Embayments of the gabbroic material in the basalt are observable on the scale of millimetres.

At point B on Figure 043.1, the gabbroic unit (border gabbro) is heterogeneous in both composition and grain size. These variations in the gabbro are irregular and are observed over distances of millimetres to metres. The composition ranges from melagabbro to leucogabbro. The grain size ranges from less than 1 mm to 3 to 5 mm, but, approaching the contact with the pillowed calc-alkalic basalt, grain size decreases to 1 mm. The contact is sharp.

SULPHIDE MINERALIZATION

Sulphide mineralization consists mainly of chalcopyrite, pyrrhotite, pentlandite, and minor pyrite and sphalerite. In their mineralogical investigation of two sulphide-mineralized hand samples, Cabri and Laflamme (1974) demonstrated that the platinum and palladium were contained in michenerite [(Pt,Pd)BiTe], sperrylite [$PtAs_2$], and cobaltite [CoAsS]. Michenerite in both samples occurs as 1 to 45 μm grains disseminated within chalcopyrite, pyrrhotite, magnetite, and pentlandite. Sperrylite was found in one of the samples as 1 to 10 μm grains within pyrrhotite, silicates, chalcopyrite, and magnetite. The cobaltite contained small quantities of platinum (0.0 to 0.2 weight percent) and palladium (approximately 0.3 weight percent).

Based on field observations, there are three settings for sulphide mineralization:

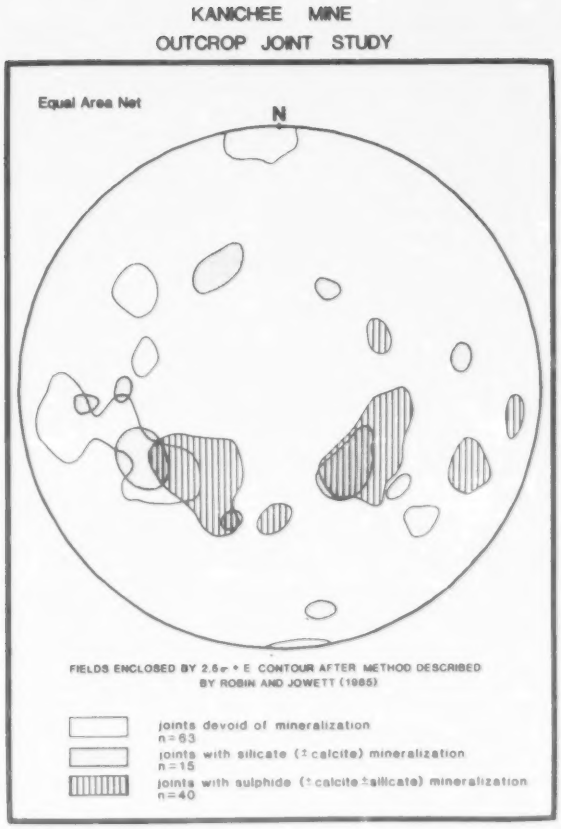

Figure 043.3. *Equal area stereonet for joints in outcrop D, Figure 043.1.*

1. evenly distributed, possibly stratabound, fine disseminated sulphide mineralization
2. massive and stringer sulphide mineralization within joints and faults
3. disseminated, fine to coarse blebs of sulphide within a halo marginal to mineralized joints and faults

Samples of olivine peridotite, pyroxenite, and gabbro were collected at a distance from the ore zone to minimize any effects of the metasomatism described by Hawke (1982), which is most intense in the ore zone.

Reinterpreted nickel and copper data for 38 samples collected away from the ore zone and analyzed by Hawke (1982) are supportive of negligible effects on sulphide compositions due to metasomatism. The mean Ni/Ni+Cu ratios for the gabbro, clinopyroxenite, and peridotite samples are 0.58±0.11 (9 samples), 0.61±0.09 (9 samples), and 0.71±0.15 (20 samples), respectively. The increasing values are related to nickel contained in both olivine and clinopyroxene.

The PGE concentrations within these least altered samples should be indicative of the magmatic PGE content, and are the subject of ongoing research.

The massive and stringer sulphide mineralization within joints and fractures are associated with calcite, talc, serpentine, quartz, chlorite, or tremolite. A study of joints in one outcrop (outcrop D of Figure 043.1) was undertaken to determine the spatial relationship between barren, sulphide-bearing, and silicate- or calcite-bearing joints. The results, as presented in Figure 043.3, indicate two dominant sets of mineralized joints that trend northeast and northwest, respectively. In general, the joint surfaces are moderate to steeply dipping; however, a very shallow dipping sulphide mineralized joint is located close to point C on Figure 043.1.

The fine to coarse, disseminated blebs of sulphide within haloes marginal to mineralized joints and faults consist of chalcopyrite, pyrrhotite, pentlandite, and pyrite. The extent of these haloes is unknown since most of the ore zone has been excavated. However, the halo to one, 1 to 3 cm thick, sulphide mineralized vein (Point C on Figure 043.1) is 10 to 30 cm thick.

PLANNED RESEARCH

A comparison of samples from each mineralization setting will focus on their PGE content with respect to the type of mineralization. If vein mineralization represents remobilized magmatic sulphides, previously resident in the ultramafic rocks as suggested by James and Hawke (1984), then a comparison between the primary and remobilized settings will shed light upon processes involved in the migration of PGE during alteration.

ACKNOWLEDGMENTS

Some independent mapping and assistance in the field was provided by B. Sifrer. R.S. James (Professor, Laurentian University, Sudbury) is thanked for his contributions to the geological map around the open pit. Eric Quaisar, (Diepdaume Mines Limited, Timmins) is thanked for his permission to work on the property. B. Paterson (Recreation Area Manager, Ministry of Natural Resources, Temagami) provided assistance for overburden stripping.

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044. Geology of the Northern Lac des Iles Complex, District of Thunder Bay

E. Linhardt and C.C. Bues

Graduate Students, University of Munich, Federal Republic of Germany.

INTRODUCTION

The field work undertaken in 1987 forms part of the second year of a program of scientific cooperation between the Ontario Geological Survey and the Institut fuer Mineralogie und Petrographie, University of Munich, Federal Republic of Germany. The investigations form part of the requirements for a Ph.D. degree by the senior author at this university. This summary reports on the results of a detailed-mapping program at a scale of 1:8000, and forms the basis for further mineralogical and petrochemical investigations.

The Lac des Iles Complex is located in the Wabigoon Subprovince of the Superior Province, approximately 80 km northwest of Thunder Bay. Road access to Lac des Iles is provided by Great Lakes Pulp and Paper Company logging roads in the Dog River area. The main access road branches off Highway 17, approximately 10 km west of Raith. The northern Lac des Iles Complex itself is easily accessible by boat.

MINERAL EXPLORATION

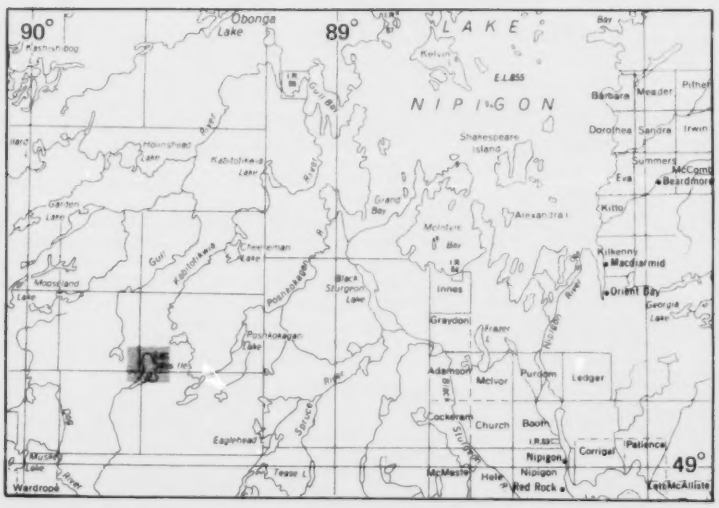
Mineral exploration dates back to the late 1950s. Economic interest in the area was initially for nickel-copper mineralization. More recently, geophysical and geological exploration, including diamond drilling and trenching, has centered on platinum group elements (PGE) mineralization. Pye (1968), Sutcliffe and Sweeny (1986), and Sutcliffe (1986) reported on these exploration efforts and the reader is referred to these publications for further information. During last year, Cream Silver Mines Limited, Equinox Resources Limited, International Platinum Corporation, and Phantom Exploration were active in the study area.

GENERAL GEOLOGY

The first detailed mapping of the Lac des Iles Complex was by Pye (1968). More recently, Sutcliffe and Sweeny (1986) mapped the Lac des Iles area and described the relationships between the rocks of the complex and the granitoid country rocks.

The northern part of the Lac des Iles Complex consists mainly of peridotites, pyroxenites, and gabbronorites. Most of the rocks, with the exception of dunites, wehrlites, and olivine clinopyroxenites, have well preserved minerals. They are neither deformed nor significantly altered. The rocks form discontinuous, lensoid to dish-shaped bodies of various thicknesses and extent. The overall distribution of the rocks and the attitude of the layering is concentric (Figure 044.1). This primary circular structure has been disrupted by several later magma injections probably at various locations. This disruption is manifested by unconformities in the northeastern part of the northern complex and by breccias and magma-mixing zones, especially in the extreme northern and southern part of the study area.

The observed layering of peridotitic rocks, followed by orthopyroxene-bearing clinopyroxenites to websterites, gabbronorites and late clinopyroxenites, suggest a crystalization path of olivine, olivine plus clinopyroxene, orthopyroxene plus clinopyroxene (±plagioclase), and/or clinopyroxene (Figure 044.2). At least five of these separate, sheetlike sequences have been observed in the field, in part disrupted by new magma pulses. Olivine cumulates occur at the base of individual sequences; these cumulates may reach 10 m in thickness, and usually contain megacrysts of clinopyroxene up to 2 cm in size. Magnetite veinlets are commonly present in the olivine cumulates. The dunites grade upwards into medium-



LOCATION MAP Scale : 1:1 584 000 or 1 inch to 25 miles.

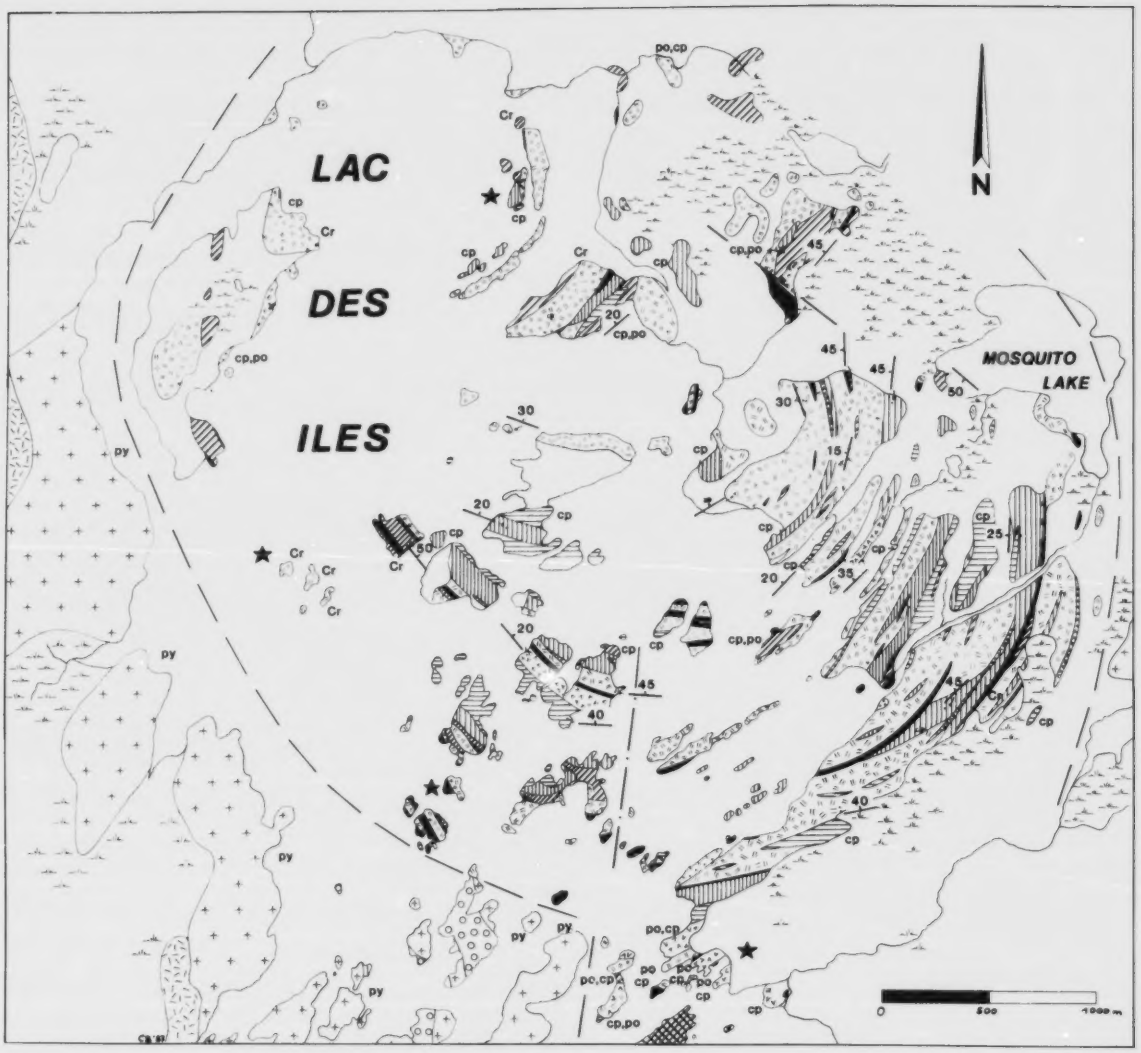
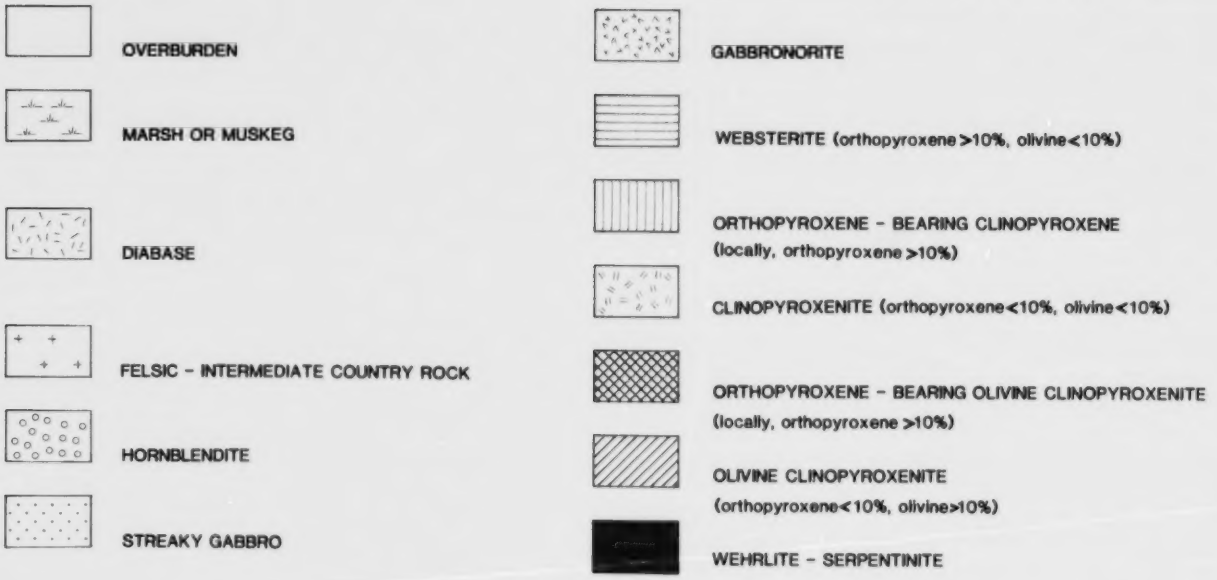


Figure 044.1. Geology of the northern Lac des Iles Complex.

to coarse-grained wehrlites and olivine clinopyroxenites which in turn grade into orthopyroxene-bearing clinopyroxenites. These rocks exhibit common, homogeneous, igneous textures. Minor interstitial plagioclase is present in some websterite and with increasing plagioclase abundance the websterites grade into melagabbronorites. Websterites are not present in all igneous sequences observed. This is believed to be due to discordant injections of clinopyroxenite crystal mushes (Figure 044.2).

Fine-scale and medium-scale igneous lamination and layering are subordinate fabrics in the northern Lac des Iles Complex. Most rocks appear to be massive and unlaminated. Where present, layering is caused by variation in modal-mineral content and in places by grain-size variations. Modal layering generally occurs in the transition zones of dunite-pyroxenite, websterite-clino-pyroxenite, and websterite-mela-gabbronorite. The modal layering at these transition zones is several centimetres to several decimetres thick; may be traced over several tens of metres; and is caused by the various modal proportions of olivine-clinopyroxene, orthopyroxene-clinopyroxene and plagioclase/pyroxenes. A more complex modal layering, exhibiting various proportions of orthopyroxene-clinopyroxene-plagioclase, was observed in places. These layers are lensoid, wispy, one to a few centimetres thick and up to a few tens-of-centimetres long. In some clinopyroxenite horizons, grain-size layering was observed. The largest clinopyroxenes are up to 1 cm in size and are aligned parallel to the layering.

Magmatic breccias suggesting magma mixing occur in many parts of the study area but are most common in the extreme northern and southern parts. The breccias consist of distinct, rounded fragments or partially absorbed, schlierenlike rocks of peridotitic



to gabbroic composition occurring in various mafic to ultramafic rocks.

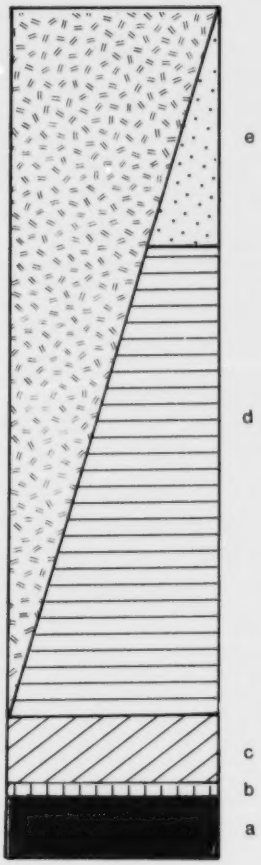
Chromite-bearing, biotite-plagioclase rocks occur in small patches of pegmatitic clinopyroxenites near contacts of magnetite-rich serpentinites with orthopyroxene-bearing clinopyroxenites. These occurrences are probably related to localized volatile activity.

In thin section, the rocks commonly exhibit xenomorphic igneous textures. Alignment of platy minerals, such as clinopyroxenes parallel to layering, was observed in only a few places. The average grain size of individual minerals commonly does not exceed 3 mm. Clinopyroxenes within both clinopyroxenites and olivine cumulates may reach several centimetres in size. Clino- and orthopyroxenes exhibit exsolution lamellae of opaque minerals and of corresponding calcium-poor and calcium-rich pyroxenes, respectively. Clinopyroxenes are anhedral; orthopyroxenes subhedral to euhedral. Relicts of olivine occur in clinopyroxenites and olivine websterites, whereas the olivines of olivine cumulates have been completely serpentinized.

ECONOMIC GEOLOGY

Pye (1968), Sutcliffe and Sweeny (1986), Sutcliffe (1986), and Linhardt and Sutcliffe (1986) have reported on the economic geology of the study area and the reader is referred to these publications for more information.

Several previously unreported sulphide-mineral and minor chromite occurrences have been observed by the authors. These are indicated on Figure 044.1. The sulphide mineralizations may contain platinum group element concentrations; as a consequence, several specimens were taken for geochemical investigations. The sulphide minerals are most common in orthopyroxene-bearing rocks and, in minor amounts, occur also in clinopyroxenites and olivine clinopyroxenites. They consist of chalcopyrite, pyrrhotite, pyrite, and subordinate pentlandite and make up commonly less than one percent of the host rocks. Richer sulphide-mineral concentrations, up to five percent chalcopyrite and pyrrhotite, were observed in one place along a marginal zone to the southern ultramafic centre, mainly in clinopyroxenites and melagabbronorites. Several specimens were taken from this occurrence for geochemical assays.



f : clinopyroxenite, predominantly medium grained, up to 100m thick

e : melagabbronorite (plagioclase less than 10%), equigranular, grain size 1 - 2mm, 10 - 50m thick

d : websterite (grain size 1 - 2mm) to orthopyroxene - bearing clinopyroxenite (grain size 1 - 3mm) up to 100m thick

c : olivine - clinopyroxenite (grain size less than 5mm), up to 10m thick

b : wehrlite, several cm thick

a : magnetite - bearing serpentinite with megacrysts of clinopyroxene, up to 10m thick

Figure 044.2. *Schematic rock sequence of the northeastern part of the Lac des Iles Complex.*

Several, previously unreported, small chromite occurrences containing up to 15 percent of chromite occur in clinopyroxenites (Figure 044.1).

ACKNOWLEDGMENTS

The present field investigations were supported by the Ontario Geological Survey and by the German Federal Ministry of Research and Technology. The German support was in the form of a grant (BZO-200LO, project 87/5, Canada-Germany technical-scientific cooperation) to G. Troll, Professor, Institut fuer Mineralogie and Petrographie, University of Munich, Federal Republic of Germany.

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045. Studies of Nipissing Intrusions in the Gowganda Area, Northeastern Ontario

D.M. Conrod

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

The Nipissing Intrusions are a suite of predominantly mafic rocks ranging from gabbronorite through gabbro to quartz diabase and granodiorite that extends from Sault Ste. Marie to the Cobalt-Gowganda area. The 2219±3.6 Ma intrusions (Corfu and Andrews 1986) have penetrated the Archean crust and intruded into either the Huronian metasediments or along the Proterozoic-Archean unconformity as primary, undulating sheets, dikes, or cone sheets.

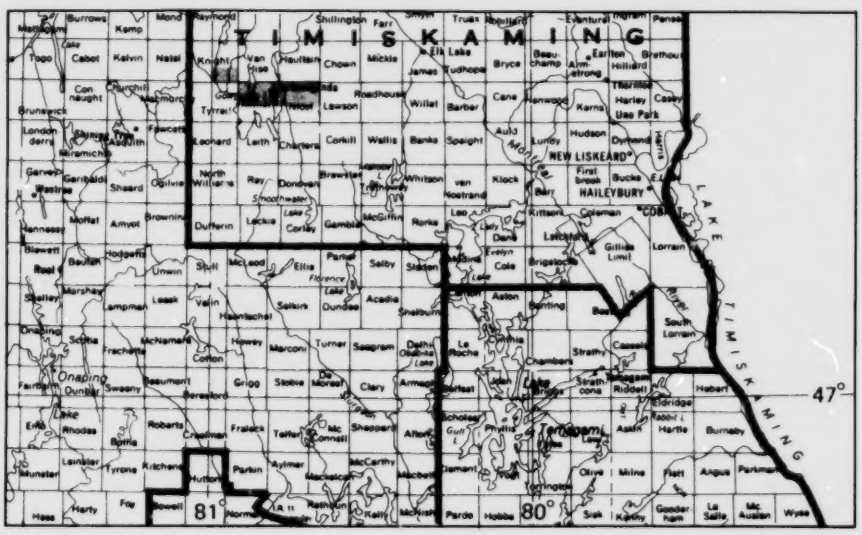
Generally, the Nipissing Intrusions have a distinct lithologic stratigraphy (Jambor 1971; Conrod, in preparation) and this stratigraphy is related to the dip of the intrusion (Conrod, in preparation). Basinal portions of undulating sheets are characterized by the presence of a capping and basal quartz diabase, a basal to central gabbronorite containing olivine in the eastern sector of the province, and an overlying variably textured gabbro containing pegmatitic gabbro pods in a finer grained gabbro matrix. Granodiorite and granophyre are present locally near the roof of a given intrusion. Steeply dipping or dikelike intrusions are characterized by bordering quartz diabase and the differentiated phases (pegmatitic gabbro and granodiorite) located in the central part of an intrusion. Chemically the intrusions are predominantly tholeiitic but they also show calc-alkalic affinities, interpreted by the author to be a result of fractionation and simultaneous contamination.

There is a spatial association between the Nipissing Intrusions and mineralization (Card and Pattison 1973; Innes and Colvine 1984). This mineralization varies in type and style from east to west: from native Ag (silver) and Co-Ni (cobalt-nickel) arsenides in quartz-carbonate veins in the Cobalt and Gowganda areas to Cu-Ni (copper-nickel) sulphides in the Sudbury area, to Cu sulphides in quartz-carbonate veins in the Sault Ste. Marie area. The mineralization in all areas predominantly occurs along the contact zones of the intrusions and the host rock (Huronian metasediments or Keewatin-type metavolcanics).

PURPOSE OF THE STUDY

The purpose of this study is to compare, petrologically and chemically, the intrusions containing mineralization with those that do not show this association in the Gowganda area, and to compare the Gowganda-area intrusions with those of the Sudbury and Cobalt areas.

A U-Pb zircon age-date will be determined by the author for a Sudbury area Nipissing Intrusion for comparison with the precise U-Pb zircon age-date determined by Corfu and Andrews (1986) for the Cobalt area intrusions. This will aid in understanding whether the differences in mineralization are age related. The petrochemical studies will aid in determining which intrusions or portions of intrusions may be mineralized.



LOCATION MAP

Scale : 1:1 584 000 or 1 inch to 25 miles

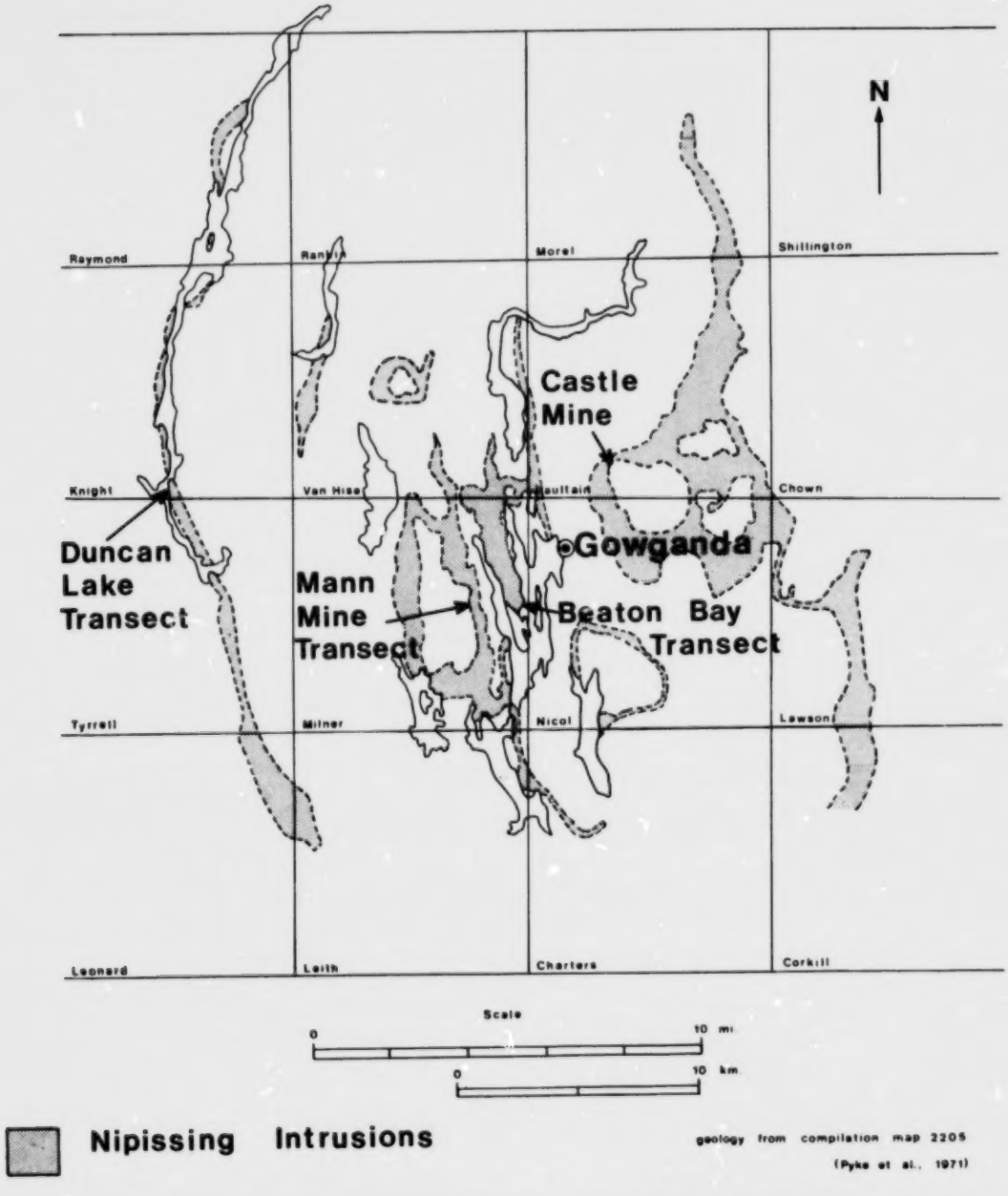


Figure 045.1. *Sample collection sites across the Duncan Lake, Milner Lake (Mann Mine), Beaton Bay, and Miller Lake (Castle Mine) intrusions.*

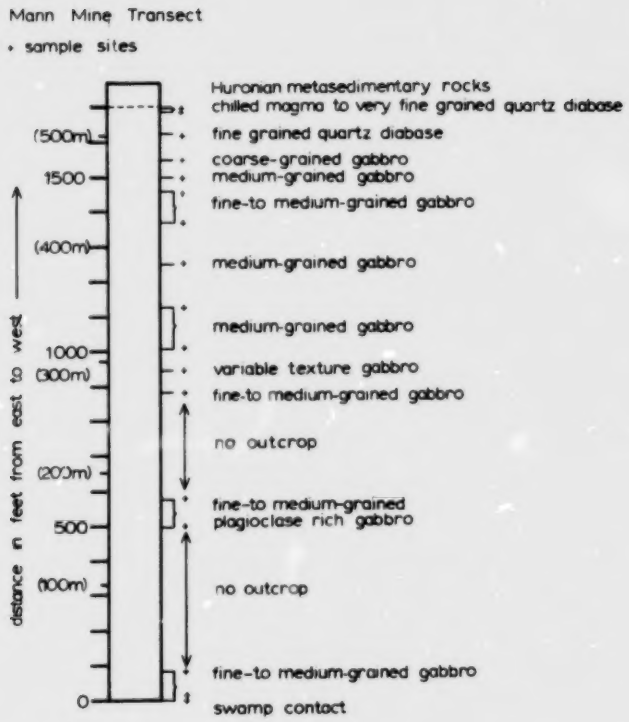


Figure 045.2. *Lithologic stratigraphy across the Milner Lake intrusion along the Mann Mine transect.*

GENERAL AND ECONOMIC GEOLOGY

This study began with detailed mapping and sampling along a transect across four different intrusions within the Gowganda area as shown on the location map and Figure 045.1.

The Mann Mine and Castle-Trethewey Mine transects are located across portions of intrusions containing mineralization. The Duncan Lake and Beaton Bay transects are located across portions of intrusions where mineralization is limited or absent.

THE MANN MINE TRANSECT

The Mann Mine transect is located across the eastern portion of an open-ring intrusion penetrating the Huronian metasediments. This portion of the intrusion dips approximately 38°W and most likely represents the eastern limb of a basin in the undulating sheet. The lithologic stratigraphy across the intrusion as determined in this study is shown in Figure 045.2.

Silver was first discovered at the site in 1908 in a 13 cm thick quartz-calcite vein trending approximately eastward. Between the years 1912 and 1952 the mine produced 118 972 ounces of silver from several veins (McIlwaine 1978). The high grade ore occurs predominantly as native silver and smaltite in calcite, but gold may also be present. According to Thompson (1968), the best silver deposits occurred near the central part of the intrusion in quartz and quartz-calcite veins. Production ceased in 1970. At the time of the current study the mine was being dewatered for future work.

THE CASTLE-TRETHEWEY MINE TRANSECT

The Castle-Trethewey Mine is located on the northwestern portion of an open-ring Nipissing intrusion penetrating Keewatin metavolcanics. The location represents the northwestern limb of a basin situated to the east. As samples could not be directly obtained through the Number 3 shaft, samples were collected at 15 m intervals along a south-southeast-trending drift on the sixth level (247 m above sea level) between the grid lines 3975 N to 2875 N and 500 W to 300 W, and along a southeast-trending drift on the tenth level (155 m above sea level) between the grid lines 2805 N to 3395 N and 2005 W to 1600 W. When these samples are projected onto a plane perpendicular to the contact planes, a complete transect through the 274 m thick intrusion was obtained with a sampling interval of 6.4 m. The lithological stratigraphy as determined from this study is shown in Figure 045.3a and 045.3b.

The mineralization (native silver, iron-cobalt-nickel arsenides, copper pyrites, and specularite) occurs in quartz-carbonate veins. From 1920 to 1931 the mine produced 6 461 021 ounces of silver. Diamond drilling by Siscoe Mines Limited began in 1971 and the mine is currently in production by Agnico-Eagle Mines Limited. Most of the ore in this intrusion was found near the upper contact of the Nipissing intrusion.

THE BEATON BAY TRANSECT

The informally named Beaton Bay intrusion is a south-southeast-trending Nipissing intrusion located between Milner Bay and Gowganda Lake. The northeasterly dipping intrusion (McIlwaine 1978) has pene-

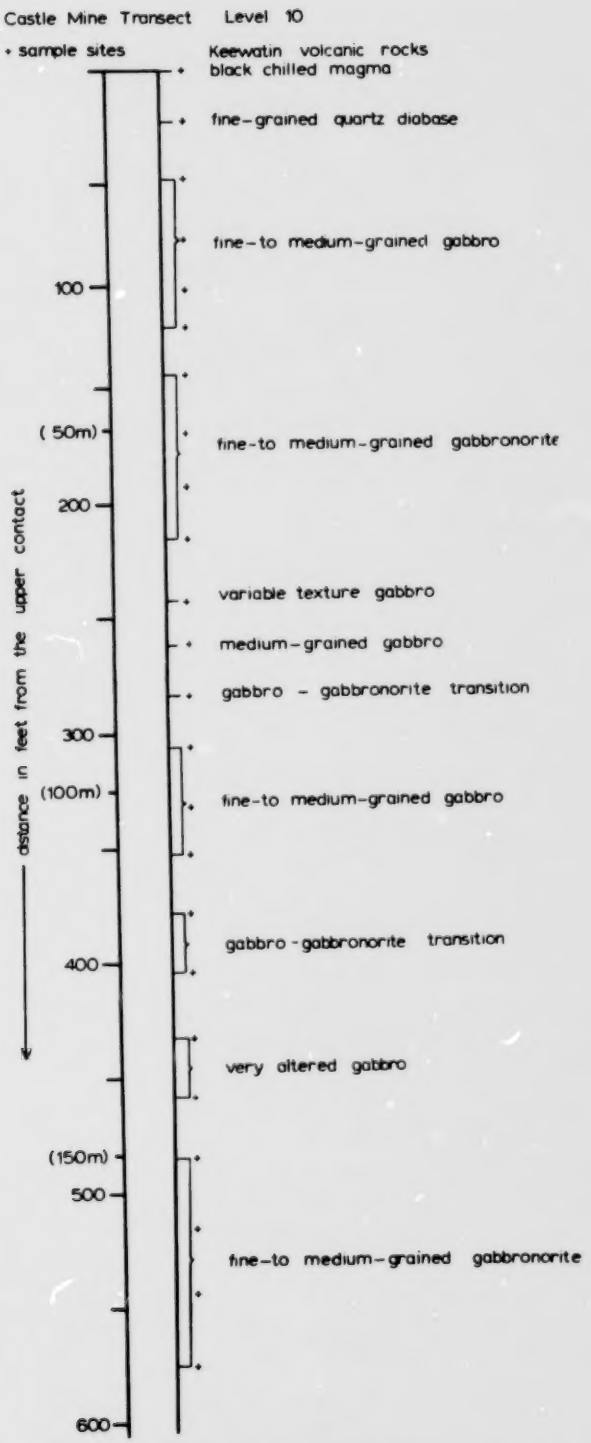


Figure 045.3a. *Lithologic stratigraphy across the Miller Lake Intrusion at the Castle Mine site. Castle Mine transect, Level 10.*

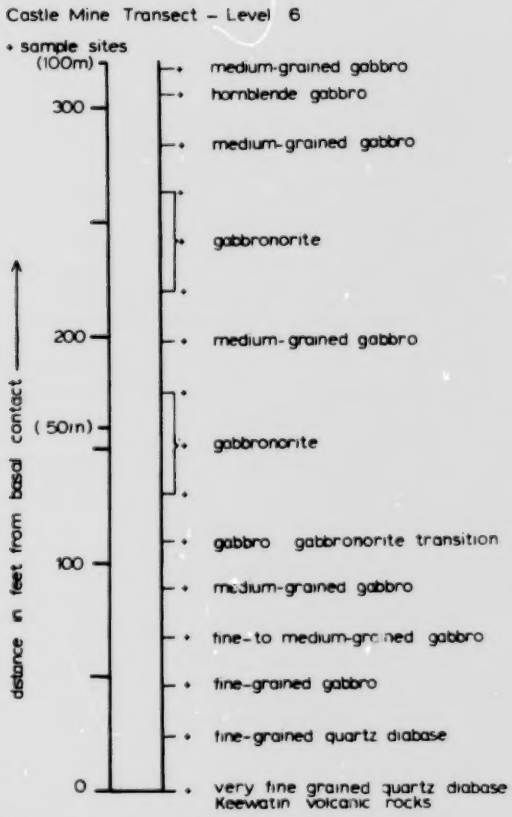


Figure 045.3b. *Lithologic stratigraphy across the Miller Lake Intrusion at the Castle Mine site. Castle Mine transect, Level 6.*

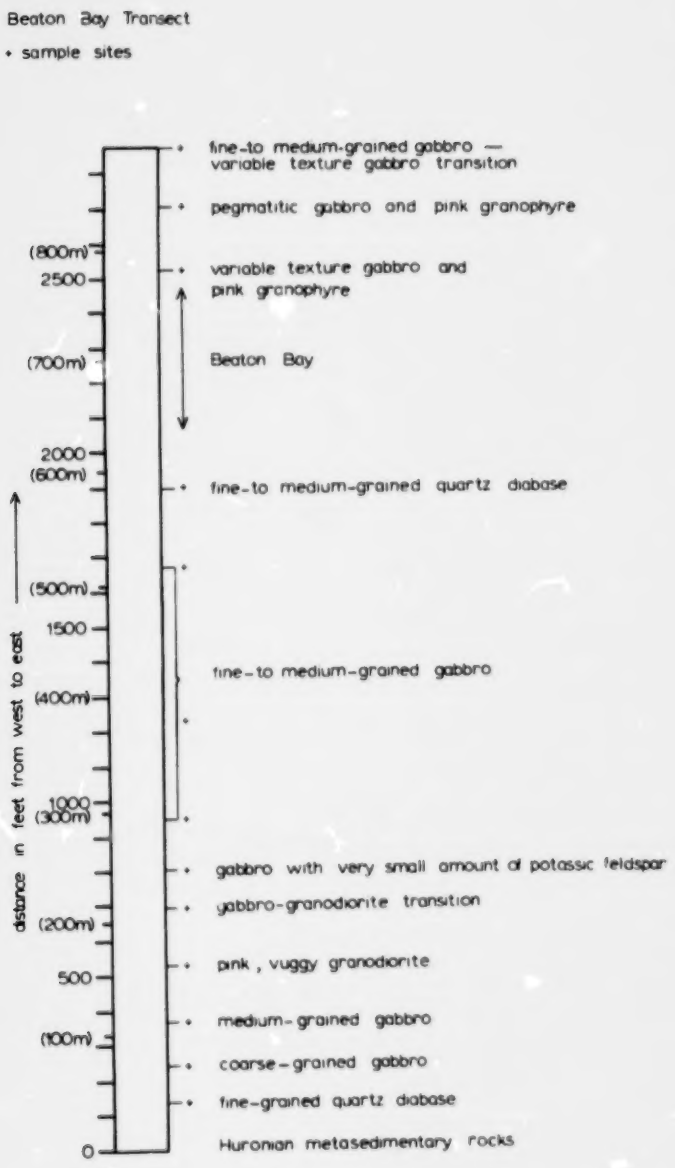


Figure 045.4. *Lithologic stratigraphy across the Beaton Bay intrusion.*

trated the Huronian metasediments. The lithologic stratigraphy is shown in Figure 045.4. Of the four intrusions considered in this study only the Beaton Bay intrusion contained a granophyric phase.

"Minor mineralization" (McIlwaine 1978) was noted in samples from diamond drilling at a site on the southeastern part of Beaton Bay. This mineralization in quartz veins proved to be of an uneconomic grade (McIlwaine 1978).

THE DUNCAN LAKE TRANSECT

The Duncan Lake intrusion is a long, gently curving, concave-eastward sill extending from the western edge of Leith Township to the eastern edge of Raymond Township. The sill dips concordantly with the Huronian metasedimentary host at approximately 25°E (Carter 1983). Samples were collected along the shoreline between Latitudes 47°40'12" and 47°40'36" and Longitudes 80°59'12" and 80°58'48" and projected onto a plane perpendicular to the contact planes. The lithologic stratigraphy is shown in Figure 045.5.

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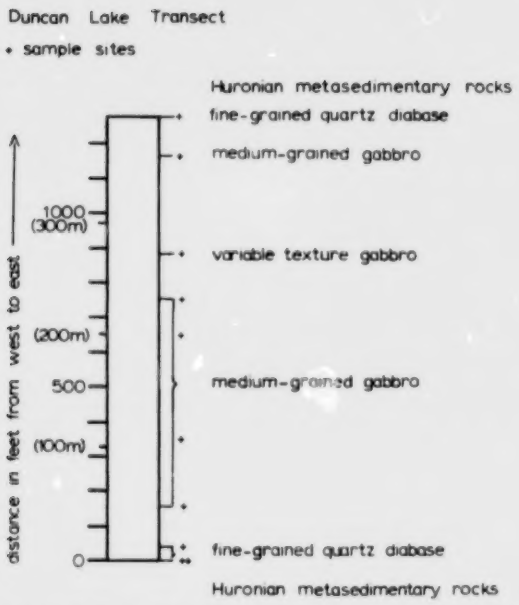

Figure 045.5. *Lithologic stratigraphy across the Duncan Lake Intrusion.*

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046. Platinum Group and Precious Metals in the Muskoka–Parry Sound Area of the Central Gneiss Belt of the Grenville Province

M.I. Garland

Geologist, Ontario Ministry of Northern Development and Mines, Dorset.

INTRODUCTION

This project is designed to study platinum group metals and precious metals in the Central Gneiss Belt of the Grenville Province in the Muskoka and Parry Sound areas of central Ontario. The goals of the project are threefold:

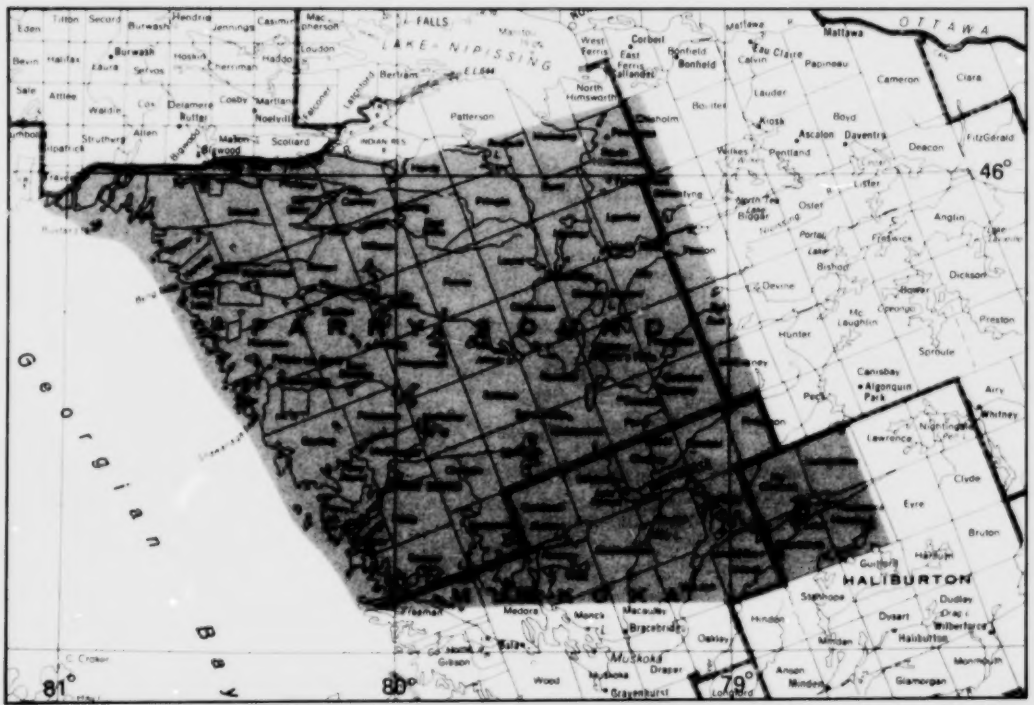
1. to compile existing information on these metals in the study area,
2. to assess the potential of the study area to host economic mineralization of these metals, in light of the current interest in them, and
3. to determine an occurrence pattern for these metals in conjunction with the evolving interpretation of the geology of the Central Gneiss Belt.

To achieve these goals, the project has been divided into three parts, including a literature survey, reconnaissance geological field work, and detailed studies of the geology of selected sites. In 1987, the literature survey and part of the reconnaissance field work have been completed.

GEOLOGY

It has been shown that platinum group metals usually occur in gabbroic and differentiated intrusions, and that they have an affinity for sulphide minerals, particularly nickel sulphides (Naldrett 1981, 1982; Naldrett and Duke 1980). Precious metals occur in a variety of rocks and are known to be associated with base metal occurrences and with shear and alteration zones. In this study, information was compiled on all known gold, base metal, and nickel occurrences, as well as information on any mafic/ultramafic rocks, such as diorite, diabase, gabbro, norite, peridotite, pyroxenite, amphibole gneiss, or garnet gneiss. Sources for this research were the assessment and commodity files in the Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Dorset; results of geological mapping by the Geological Survey of Canada (Davidson and Morgan 1981; Davidson *et al.* 1982; Culshaw *et al.* 1983; Davidson *et al.* 1985; Davidson and Grant 1986); and reports by the Ontario Government (Coleman 1899, 1900; Satterly 1942; Hewitt 1967; Villard *et al.* 1984; Marmont and Johnston 1987).

In the Muskoka-Parry Sound area, there are approximately 100 reported occurrences of base metals, primarily copper-nickel and/or gold, and several



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

known mafic/ultramafic rock types. Although small, many of the occurrences have undergone exploration work of some type. Ore was extracted from some of these, notably the Wilcox Copper Mine and the McGown Gold-Copper Mine near Parry Sound. A wide variety of terminology has been used to describe the mafic/ultramafic rocks in the area, with the result that all require a geological examination to confirm their characteristics. Work in the area has revealed that some of the lithologies described as amphibole-garnet gneiss, amphibole gneiss, or diorite are actually gabbroic intrusions. Some of the mafic intrusions are currently undergoing exploration for platinum group metals. Many of the base metal occurrences have never been assayed for platinum group metals, gold, or silver.

CONTINUING WORK

Samples from the occurrences examined during the 1987 program are being analyzed for platinum group metals and precious metals. Whole rock analyses and petrographic studies will be carried out to aid in determining the lithologies. The results from this work will be published in an open file report in the spring of 1988.

ACKNOWLEDGMENTS

The author would like to thank Graham Wilson for organizing a tour of the Caribou Lake area, and Teck Corporation for allowing access to their files.

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047. Kaolinite in Northeastern Ontario

M.J. Ford

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Kaolinite ($Al_4Si_4O_{10}(OH)_8$) and its polymorphs form an important group of industrial minerals, collectively referred to in industry as kaolin or china clay, with uses that include paper coating, filler applications, ceramics, and refractories. Canada does not produce kaolin commercially and its requirements are supplied from abroad, mainly the southeastern United States and Great Britain. In Ontario, deposits of kaolinitic silica sand and refractory clay in the Moose River Basin were recognized in the late 1800s and were studied by government geologists in the first decades of this century (e.g. Bell 1904; Keele 1920; Montgomery and Watson 1929; Dyer and Crozier 1933). These and more recent studies are summarized in Vos (1982), along with a useful discussion of kaolinite, its processing and uses. Kaolinite of probable Late Cretaceous to Early Tertiary age also has been found overlying the Cargill Township Carbonatite Complex southwest of Kapuskasing (Sandvik and Erdosh 1977; Springer 1986).

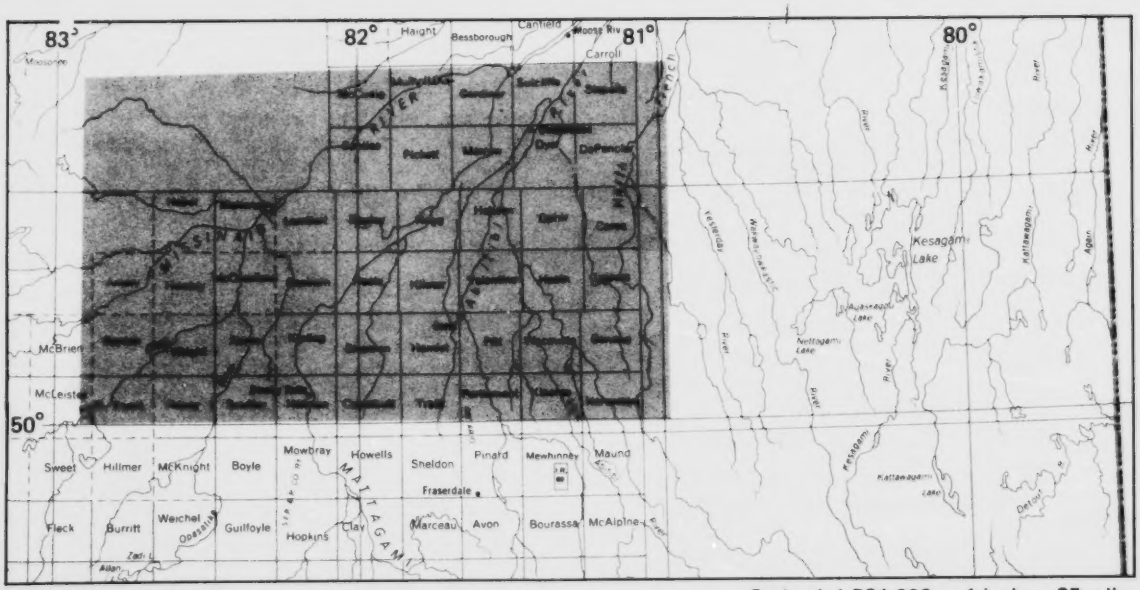
GENERAL GEOLOGY

The Moose River Basin lies in the southern part of the James Bay Lowlands and is underlain by sedimentary rocks of Paleozoic and Mesozoic age. The entire area is thickly mantled with Quaternary sediments and older rocks are visible only along streams. The basin is fault-bounded on the south by rocks of the Archean Superior Province. Within the Moose River Basin, the kaolinite-bearing Mattagami Formation underlies an area of about 10 000 km^2 (Telford 1982). Based on palynological data, Norris (1982) has suggested a Middle to Late Albian (latest Early Cretaceous) age for the Mattagami Formation. It rests unconformably on Devonian marine sedimentary rocks except locally where clastic sediments of probable Jurassic age occur (Telford 1982). The Mattagami Formation consists of well-stratified quartz sand and fine pebble gravel, commonly with a kaolinitic matrix, varicoloured silts and clays, and lignite. Outcrop is sparse and drill hole data have been used to delimit its areal extent and aid interpretation of depositional environments.

Try *et al.* (1984) have suggested that the Mattagami Formation sediments are products of deposition in a vertically aggrading, anastomosing stream system. As evidence, they cite vertical sequences of stacked, steep-walled channel deposits composed of sands and minor gravels and flanked by fine-grained sediments. These authors consider this interpretation provisional due to the limited number of outcrops available and the lack of lateral facies control between widely spaced bore holes.

KAOLINITE DEPOSITS

The clay minerals of the kaolinite family develop by the chemical breakdown of aluminum-bearing silicates, principally feldspars, either in a weathering environment or by hydrothermal alteration. Significant subaerial kaolinization requires an acidic environment and a humid, tropical to subtropical climate, conditions that were probably present in the Moose River Basin during the Late Mesozoic (Hallam 1985). In the Mattagami Formation, kaolinite forms a pervasive matrix to the quartz sands and pebble gravels, ranging in volume from 10 to about 30%. This intimate mixture of silica sand and kaolinite suggests *in situ* development from an original quartzo-feldspathic



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

TABLE 047.1. LOCATION OF DRILL HOLES.

Drill Hole No.	Core Library No.	Collar Elev. (m)	Lat.	Long.	No. of Samples
OGS 78-3	T1-2274	120	50.200	80.739	1
OGS 78-5	T1-2276	110	50.167	83.078	2
OGS 83-3	T1-0024	73.2	50.725	81.983	1
OGS 84-4	T1-0025	95	50.956	82.092	1
OGS 84-5	T1-1008	152.4	50.431	82.937	2
OGS 84-8	T1-1011	125	50.229	83.083	10
OGS 85-1	T1-2016	56.8	50.589	81.486	1
OEC 81-1	T1-0461	55	50.562	81.585	1
OEC 81-5	T1-0462	67.1	50.492	81.642	3
OEC 81-10	T1-0465	62.5	50.677	81.718	1
ONEX W 83-13	T1-2012	91.1	50.489	82.074	2

sediment, rather than introduction of the kaolinite following deposition of the sand. The hydrodynamic differences between clay-sized kaolinite and quartz sand preclude simultaneous sedimentation. Relict feldspar grains, partly replaced by kaolinite, are present locally (Try 1984). Kaolinite is also present in bodies of compact clay which Try *et al.* (1984) interpret as flood plain deposits. They suggest that light-coloured clays must have been under oxidizing conditions long enough for complete oxidation of organic matter. These compact kaolinitic clays have been referred to by others as "white fire clays" (Guillet and Joyce 1987). The material for these clay deposits was derived either from the original sediment source regions or by reworking kaolinitic silica sand deposits.

PRESENT STUDY

This year's activities involved sampling kaolinite from drill core and examining selected samples with a scanning electron microscope (SEM). Also, exposures of Cretaceous sediments were examined and sampled along Adam Creek near the southern margin of the Moose River Basin. All samples have been submitted for grain-size and major oxide analysis and mineral identification by X-ray diffraction. The bore hole samples were obtained at the Timmins Drill Core Library, Ministry of Northern Development and Mines, from material gathered during drilling programs in the James Bay Lowlands by the Ontario Geological Survey, the Ontario Energy Corporation, and Onexco Minerals, Limited. The drilling methods used were triple tube coring and reverse circulation. Logs for about 50 holes were checked and suitable sections of core were examined and sampled from eleven of these drill holes. Drill hole locations are given in Table 047.1.

One problem encountered during sampling was the poor representation of kaolinitic silica sand. Despite its clay content, this material generally has poor cohesion and is very difficult to recover by triple tube coring. The sandy horizons were usually drilled by reverse circulation and most of the kaolinite was lost. Few reverse circulation samples are archived at the Timmins facility and only traces of kaolinite could be found in the available samples. Most of the sampled kaolinite came from core sections of compact, white to pale grey, clay.

SEM STUDY

Scanning electron microscopy was used to investigate some of the physical characteristics of the kaolinitic clays, such as grain size and grain morphology. Many of kaolinite's uses are governed by size range, aspect ratio, and grain margin configuration, although some of these properties can be improved during processing by size classification and delamination. The SEM technique using secondary electrons is relatively fast and inexpensive; sample preparation is easy, and image interpretation is straight forward. The instrument used was a Jeol JSM 840 located in the Department of Geology, University of Toronto. It was operated at 15 to 20 kV with a beam current of 3×10^{-11} to 6×10^{-10} A.

Eighteen samples were examined, including a specimen of high quality Georgia Kaolin and outcrop samples from Kipling Township and the Cargill Complex. A summary of observations is given in Table 047.2 and major oxide analyses for some of the samples are listed in Table 047.3. In general, the Ontario samples tend to be coarser grained than the kaolinite from Georgia. Many of the anhedral micaceous grains could not be positively identified. All the samples require chemical analysis and min-

TABLE 047.2. SUMMARY OF SEM STUDIES.

Samples not taken from Moose River Basin drill holes: (1) Cargill Township Carbonatite Complex (2) East side of Mattagami River, about 0.5 km north of Kipling Dam, Kipling Township (3) Georgia kaolinite. Agg. denotes size of grain aggregates.

Sample No.	Drill Hole No.	Depth (m)	Grain Size (microns)	Comments
85-0001 (1)	-	-	-	Many high aspect flakes, ragged margins
85-0104 (2)	-	-	10-20, 75	Thick grains with good visible cleavage - kaolinite "books"
85-0105 (2)	-	-	5-30 (max)	High aspect, ragged grain margins
85-0107 (2)	-	-	0.5-2, 10 (max)	High aspect, ragged grain margins
87-0001	OGS 84-5	92.2	2-10, 40 (agg)	High aspect grains, mainly ragged margins, a few euhedra kaolinite
87-0002	OGS 84-5	102	<1-20	Mixture of minerals, very little kaolinite
87-0003	OGS 84-8	107	3-10, 20+ (agg)	Moderate to high aspect grains in aggregates
87-0006	OGS 84-8	126	1-8, 15+ (agg)	Moderate aspect grains, irregular margins, no euhedral crystals
87-0008	OGS 84-8	127.8	1-8	Grains have irregular margins, few high aspect flakes present
87-0009	OGS 84-8	131.6	1-15	Abundant high aspect grains, ragged margins; sparse acicular grains of unknown type
87-0001	OGS 84-8	142	1-4, 20 (max)	Moderate to high aspect, no euhedral grains
87-0014	OGS 84-4	86.7	100 +	Very little micaceous material
87-0015	OGS 78-5	74.5	2-15	Polymineralic, no euhedral kaolinite
87-0017	OGS 78-3	78	2-5	Mainly thin, anhedral flakes with possible illite
87-0018	OGS 85-1	79.5	1-8	Anhedral grains with distinct cleavage, moderate number of thin flakes
87-0021	ONEX W83-13	114	5-10, 15-30 (agg)	Mixture of kaolinite and other minerals, aggregates of high aspect, anhedral kaolinite
87-0026 (2)	-	-	5-20, 30+ (agg)	Mainly high aspect kaolinite
87-0030 (3)	-	-	<2, 15 (agg)	Abundant high aspect, kaolinite flakes and euhedral kaolinite "books"

TABLE 047.3. MAJOR OXIDE ANALYSES FOR SELECTED KAOLINITE SAMPLES.

	1	2	3	4	5	D
SiO_2	43.7	50.9	52.3	59.4	53.5	43.6
Al_2O_3	37.7	32.9	30.7	27.6	31.9	37.6
Fe_2O_3	0.58	1.12	1.66	0.52	0.56	0.47
MgO	0.11	0.11	0.02	0.10	0.06	0.08
CaO	0.22	0.18	0.25	0.12	0.13	0.21
K_2O	0.00	0.30	0.05	0.54	0.30	0.00
TiO_2	2.30	0.71	1.48	0.47	0.45	2.31
P_2O_5	0.43	0.07	0.07	0.04	0.03	0.42
MnO	0.02	0.03	0.01	0.01	0.01	0.02
CO_2	0.23	0.43	0.41	0.43	0.41	0.42
L.O.I.	13.9	12.3	12.3	10.3	11.8	14.2
TOTAL:	99.0	98.6	98.8	99.1	98.7	98.9

Sample numbers: (1) 85-0001, (2)85-0104, (3) 85-0105, (4) 85-0106, (5) 85-0107, (D) duplicate of 85-0001. Analysis was by X-ray fluorescence on the -230 fractions. Sample 85-0106 is from the Kipling Dam Area.

eral identification by X-ray diffraction for proper characterization. Examples of the SEM images are shown in Photos 047.1 to 047.4.

CRETACEOUS OUTCROPS ALONG ADAM CREEK

Adam Creek is a northerly flowing tributary of the Mattagami River, located about 90 km north of Kapuskasing in Kipling and Harmon Townships. The creek is used as a diversion channel by Ontario Hydro from its reservoir in Harmon Township. The stream is deeply incised with bluffs about 15 m high. The sporadic high water levels, especially during spring runoff, renew exposures of unlithified Quaternary and Cretaceous sediments by clearing away slump debris and exposing fresh material. In past years, excellent exposures have been available for examination, such as during the Ontario Geological Survey lignite studies in 1978 (Verma and Telford 1978).

Because of low runoff during the past spring, many of the bluff sections were heavily slump-covered. Only two exposures with undisturbed Cretaceous sediments were found in a canoe traverse of the lower eight kilometres of the creek in August. One of these sections included Verma and Telford's (1978) "main lignite outcrop" (UTM 223592, 42J/1). This section contains up to three metres of horizontally bedded and tabular cross-stratified kaolinitic quartz sands and pebbly sands overlying dense, very dark grey to black carbonaceous clays. The cross-bedding occurs in sets 40 to 50 cm thick. The contact with the underlying clays is sharp and erosional and was traced laterally for about 40 m; the upper contact was slump-covered. In other exposures along the creek, Mesozoic sediments were observed that had been incorporated into glacial till of Quaternary age, either as large, weakly to moderately deformed blocks or as thin, drawn out lenses and bands.

DISCUSSION

The preliminary results of this study suggest that, in terms of grain attributes and chemistry, there is potential to find a source of high quality kaolinite in Ontario. These findings complement previous work (*see* Vos 1982; Guillet and Joyce 1987) which has tended to emphasize the ceramic properties of the clays. At the Cargill Complex, the kaolinite has attractive ceramic properties (Springer 1986), is of fairly high chemical purity, and is associated with a large phosphate deposit. Drill hole records on file with the Assessment Files Research Office, Ontario Geological Survey, Toronto, indicate local thicknesses of kaolinitic material of up to 100 m at Cargill. This kaolinite could be a valuable co-product of phosphate production and warrants further investigation. The samples from the Kipling Dam area, although apparently not of the same chemical purity as the material from Cargill, are very fine-grained with abundant, high aspect flakes. Beneficiation may be able to improve the mineralogical purity of this material but this requires proper investigation. In 1985, Carlson Mines Limited took a large bulk sample of kaolinitic silica sand from a site in Kipling Township but the results of tests on this material are not available.

The present study was hampered by the limited number of drill hole samples available for testing. This serves to point out the major problem with evaluating the kaolinite resources of the Moose River Basin: too little data from widely scattered locations. This is largely due to the remoteness of the region and the difficulty and expense of carrying out drilling there. Also, most drilling programs in the basin have been aimed at assessing lignite resources. Sampling of kaolinite was secondary and usually inadequate, partly because of technical problems. Future studies should concentrate on relatively accessible parts of the basin where overburden is thin enough to make open pit mining a possibility. In some parts of the area, such as at Onakawana, overburden thickness is fairly well known, but for most of the basin this is not the case. Because the kaolin-bearing quartz sand bodies are channel fills, delineation of paleochannels

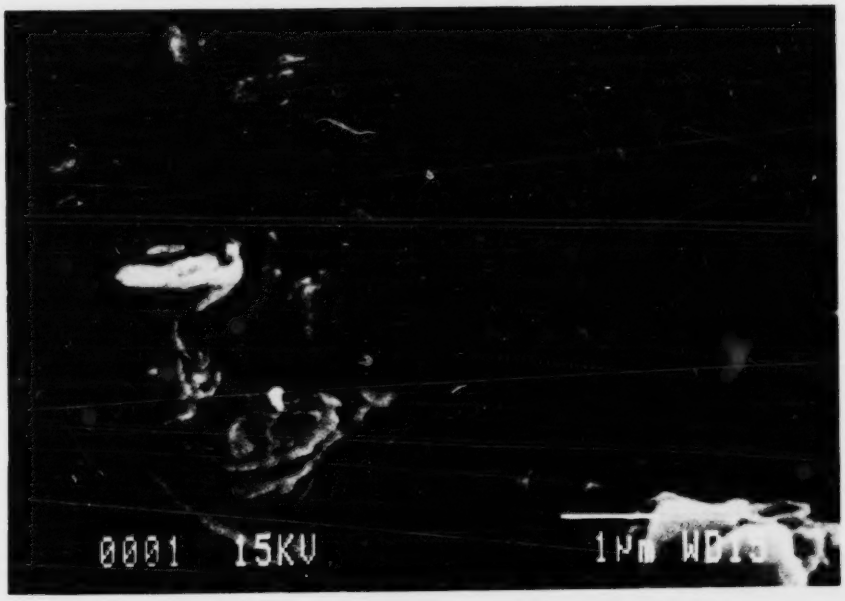


Photo 047.1. *Sample of Georgia kaolin. Note the abundance of euhedral crystals, the high aspect ratios of the flakes, and the fine-grained nature of the material. Scale bar 1 micron.*

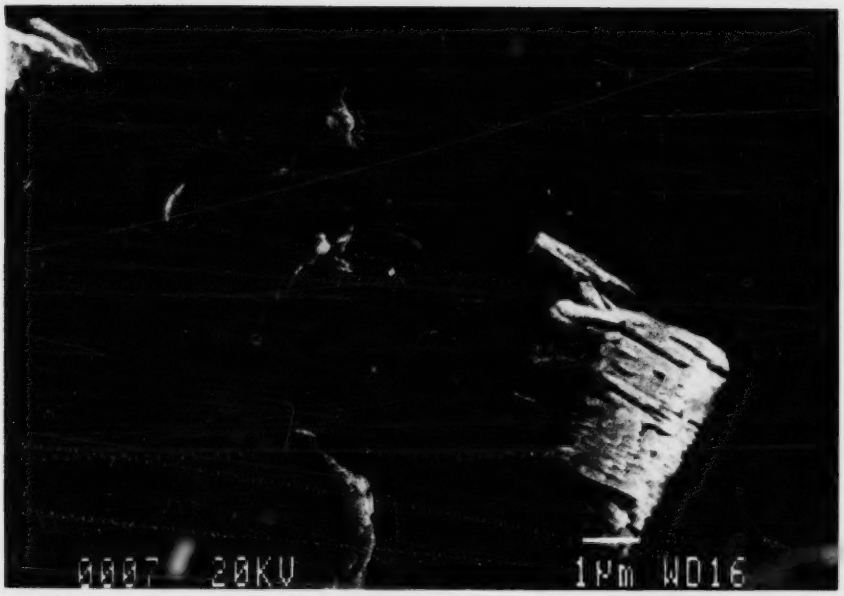


Photo 047.2. *Sample 87-0001. Well-formed "books" of kaolinite are prominent. Scale bar 1 micron.*

within the Mattagami Formation would be helpful. Geophysical techniques, such as resistivity and seismic methods, could be useful for tracing channels in the subsurface but are largely untested in the Moose River Basin. Regardless of the method used, care must be taken in sampling kaolinitic sediments to prevent contamination by other materials.

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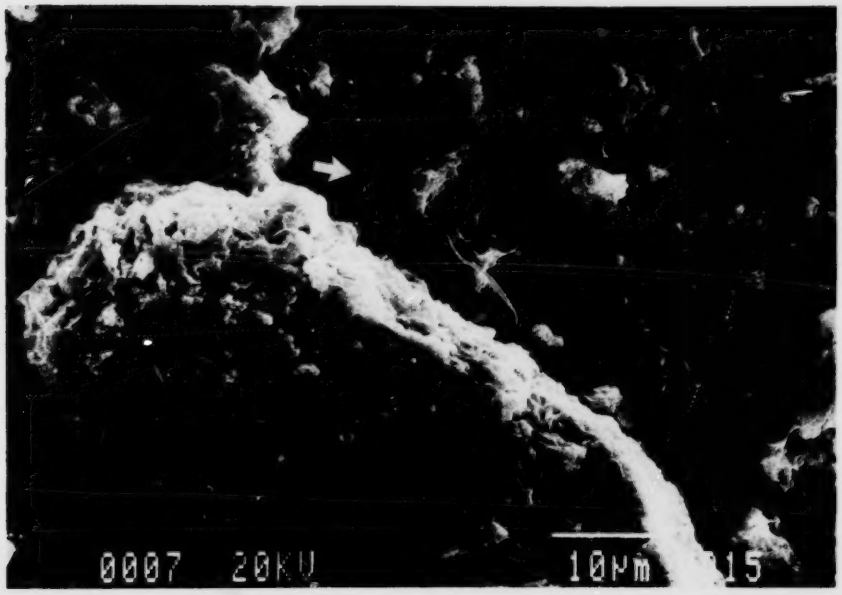

Photo 047.3. *Sample 85-0001. Mainly irregular grains with distinct basal cleavage. Note the kaolinite book (arrow). Scale bar 10 microns.*

Photo 047.4. *Sample 87-0021. An aggregate of randomly oriented, anhedral grains of only moderate aspect but with distinct cleavage. One grain of euhedral kaolinite is present (1) and an acicular grain of unknown type (2). Scale bar 10 microns.*

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048. Komatiite–hosted Talc in the Tudor Formation, Elzevir, Madoc and Grimsthorpe Townships, Southeastern Ontario

P.S. LeBaron[1], A. MacKinnon[1], and P.W. Kingston[2]

[1]Geologist, Ontario Ministry of Northern Development and Mines, Tweed.

[2]Resident Geologist, Ontario Ministry of Northern Development and Mines, Tweed.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

Previous studies of talc in the Tudor Formation, by Verschuren (1982) and Dillon and Barron (1985), outlined several areas of potentially economic talc mineralization. Verschuren noted the possibility that the volcanic-hosted talc bodies are altered komatiitic flows or sills. The same hypothesis has since been substantiated for talc, magnesite, and asbestos deposits in the Timmins-Kirkland Lake area by Kretschmar and Kretschmar (1986).

Previous geological maps of the area studied for this report (Meen and Harding 1942; Hewitt 1968) have divided the metavolcanic rocks into two groups: mafic metavolcanic rocks and felsic metavolcanic rocks. In order to provide a guide to exploration for talc, the 1987 field program was undertaken to further subdivide the mafic volcanic rocks into ultramafic komatiites, komatiitic basalts, and tholeiitic basalts, and to map the known talc-bearing zones beyond the boundaries of previous surveys.

1987 SURVEY AREA

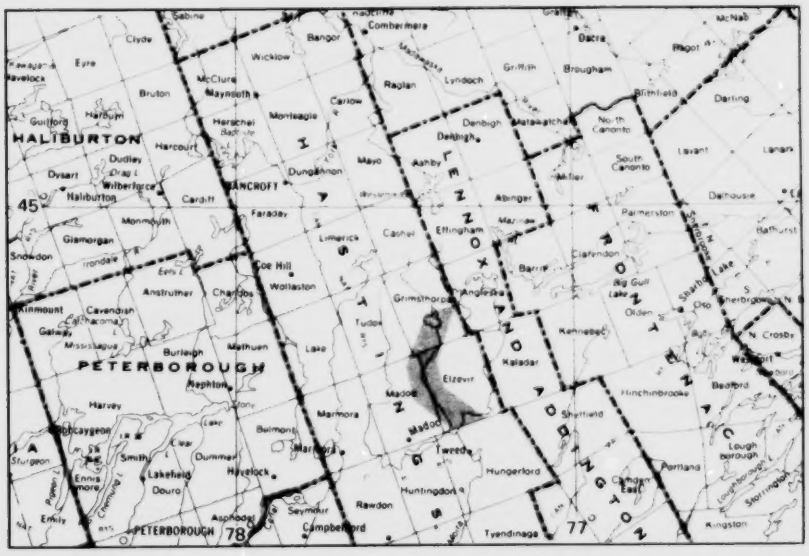
The survey area extends from Highway 7 in Elzevir Township northward along the western margin of the Elzevir Batholith to the northern end of Lingham Lake in Grimsthorpe Township. Paved and gravel roads cross the map area in Elzevir Township, but access in Grimsthorpe Township is poor.

Mapping was carried out during the 1987 field season by P.S. LeBaron, with assistance from V. Bernard. An aerial photograph, scale 1:10 000, was used as a base, with traverse intervals ranging from 200 to 600 m, depending upon access and lithologies encountered.

Field classification of rocks was supplemented by whole rock analysis done by X-Ray Assay Laboratories (XRAL) of Don Mills, Ontario. Jensen Cation Plots of the analytical results were also produced by XRAL. Thin section studies had not been completed at the time of writing.

MINERAL EXPLORATION

Prospecting in the study area began over 100 years ago, following the discovery of iron, gold, copper, lead, and talc deposits in Madoc Township in the late 1800s (Hewitt 1968). This activity resulted in the discovery of the talc deposits in Elzevir Township, which were later traced northward into Grimsthorpe and Cashel Townships. Some of the more promising showings were tested by trenching and diamond drilling, but the high cost of beneficiation of the relatively



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

impure volcanic-hosted talc ore prevented further development.

In the early 1980s, interest in the area was revived because of increased use of lower quality talc as an industrial filler, with several prospects being evaluated by Steep Rock Iron Mines Limited, Canada Talc Industries Limited, and Twin Buttes Exploration Inc.

No exploration activity has been recorded in 1987, but several claims were staked in the map area, and interest continues in exploration for talc as well as in the potential for gold mineralization within the komatiitic-tholeiitic volcanic sequence.

REGIONAL GEOLOGY

The study area is located within the Central Metasedimentary Belt of the Grenville Province in southeastern Ontario (Wynne-Edwards 1972), more specifically, within the Hastings Basin (Lumbers 1967).

The oldest rocks in the Hastings Basin are the mafic metavolcanics (Tudor Formation), felsic metavolcanics (Oak Lake Formation), and associated metasediments of the Hermon Group. These are overlain by clastic and carbonate metasediments of the Mayo Group (Lumbers 1967). Diorite-granodiorite and syenite-monzonite complexes intrude all of these rocks, with associated thermal metamorphic aureoles that raise the metamorphic grade in the map area to amphibolite facies from the regional greenschist facies of the Hastings Basin.

Unconformably overlying the Hermon and Mayo Groups are clastic metasedimentary rocks of the Flinton Group, predominantly quartzite, wacke, and conglomerate.

Locally overlying the Precambrian rocks are small outliers of Paleozoic (Ordovician) limestone of the Black River Group.

The Precambrian rocks have been subjected to several phases of deformation, the most recent major event being the Grenvillian Orogeny. The resulting structural pattern is very complex. The dominant trend of the metavolcanic and metasedimentary rocks is northeasterly; major faults in the area trend northwesterly.

GEOLOGY OF THE STUDY AREA

GENERAL GEOLOGY

The map area (Figure 048.1) follows the western margin of the Elzevir Batholith through Elzevir, Madoc, and Grimsthorpe Townships. Mafic volcanic rocks of the Tudor Formation are wrapped around the granodiorite intrusion, striking roughly parallel to and dipping away from it to the south and west.

The 1987 field survey was initiated to test Verschuren's (1982) hypothesis that the talc occurrences are in altered komatiitic rocks. As a working hypothesis, the mafic volcanic rocks were divided in the field into ultramafic komatiite, komatiitic basalt, and tholeiitic basalt, based upon their alteration mineralogy. The magmatic parentage of the rocks was then determined from analyses of samples of each rock type. A Jensen Cation Plot (Figure 048.2) of analyses of 51 samples from the map area shows the transition from komatiites to tholeiites, corresponding to the change in composition of the metavolcanics westward from the Elzevir Batholith.

The komatiites, host to the talc occurrences of the area, form a band from 400 to 2000 m wide along the western margin of the batholith through the southern part of Elzevir Township, extending into Madoc Township. These are overlain by a series of tholeiitic flows, ranging from magnesium-rich to iron-rich, and minor interflow sediments and tuffs.

Tholeiitic rocks are predominant northeastward along the batholith's margin into northern Elzevir and southern Grimsthorpe Townships, and komatiites occur only as thin, discontinuous layers within the tholeiitic sequence.

DESCRIPTION OF MAP UNITS

Unit 1. Ultramafic Komatiite

The ultramafic komatiites occur as a series of flows and possibly sills, forming thicknesses ranging from 5 to 200 m. They occur at various levels within the basaltic komatiite sequence, but are concentrated in two main zones, one along the contact of the Elzevir Batholith and the other near the top, or western limit, of the komatiite sequence.

Alteration assemblages within the ultramafic rocks range, in increasing intensity, from actinolite-tremolite to serpentine-magnetite and talc-chlorite-carbonate-magnetite. The actinolite-rich rocks are generally weakly foliated with medium- to coarse-grained, radiating, fibrous amphiboles. Talc-chlorite rocks are schistose and commonly strongly sheared, often containing minor amounts of red hematite in the shear zones. The rocks are very soft, weathering with a smooth, brown to green-grey surface where actinolite-rich; and with a rusty-red to grey, pitted surface where talc, carbonate and hematite are present.

Primary volcanic structures are not well preserved. Brecciated zones seen in some outcrops may represent flow-breccia. In the Flinton Road area, repeated sequences of fine-grained chlorite-magnetite, coarse actinolite-carbonate, and fine actinolite-carbonate, each sequence being about 3 m wide, appear to represent consecutive ultramafic flows that have undergone some flow differentiation. The chlorite-magnetite upper zone is of basaltic komatiite composition; the coarse actinolite central zone and fine-grained lower zone are ultramafic komatiite in composition. Such compositional zoning will produce variations in talc content within talc-carbonate-chlorite-altered ultramafic rocks.

All of the talc zones shown on Figure 048.1 are considered to be altered ultramafic komatiites.

Unit 2: Komatiitic Basalt

The komatiitic basalts form a band which follows the contact of the Elzevir Batholith, ranging in width from 400 m in southern Elzevir Township to 2000 m in Madoc Township. This unit terminates abruptly in northwestern Elzevir Township, interfingering with

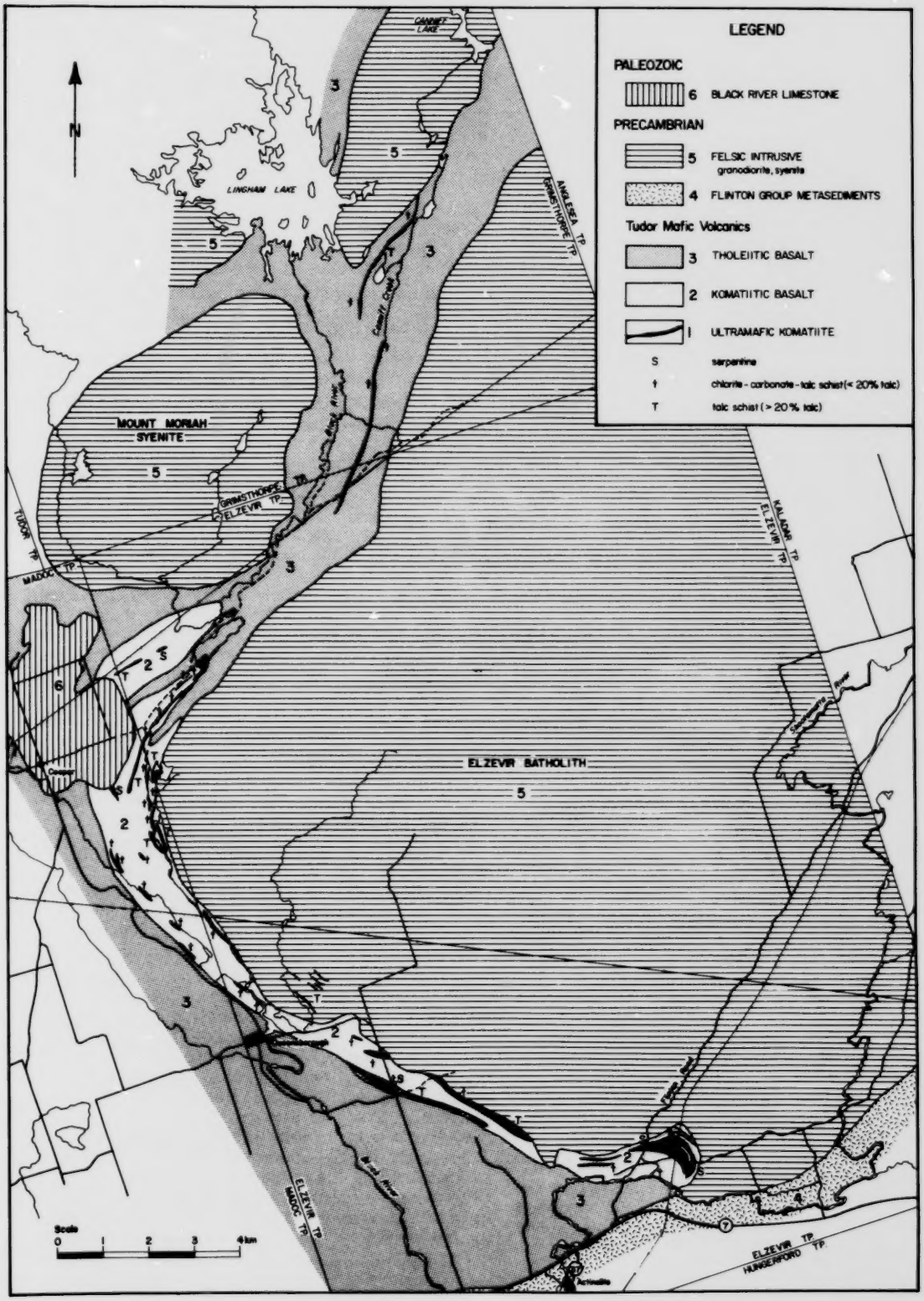


Figure 048.1. *Generalized geology of the study area.*

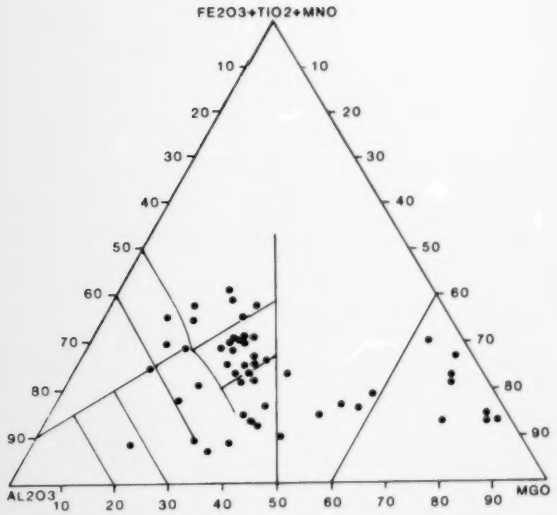


Figure 048.2. *Jensen Cation Plot showing (a?) compositional trend(s?) within the metavolcanic rocks of the Tudor Formation.*

tholeiitic basalts which extend into southern Grimsthorpe Township.

Metavolcanic rocks of this unit generally consist of actinolite, with lesser amounts of hornblende and plagioclase. Texturally, they vary from fine-grained and weakly schistose, to coarse-grained porphyroblastic rocks with segregated bands of plagioclase and actinolite-hornblende. They are slightly softer than the tholeiitic rocks and are dark green with a serpentinous sheen on slip surfaces.

Where strongly altered, the komatiitic basalts may be altered to chlorite-carbonate schist with minor serpentine and traces of talc.

Unit 3: Tholeiitic Basalt

Tholeiitic basalts overlie the komatiitic rocks in southern Elzevir and eastern Madoc Townships. They are interfingered with the komatiites in northern Elzevir Township, extending northward into Grimsthorpe Township where only a few, thin, ultramafic flows occur within the tholeiitic sequence.

The tholeiites are essentially hornblende amphibolites, fine to medium grained, dark green to black, and massive to weakly foliated. In northern Elzevir and southern Grimsthorpe Townships, the tholeiites are altered to a porphyroblastic, gneissic rock, with segregated mafic and felsic bands, which can be distinguished from similarly altered komatiitic basalt by its greater hardness and higher plagioclase content.

Thick (up to 20 m) sections of mafic lapilli tuff and agglomerate occur within the tholeiitic sequence along with thin units of felsic tuff and rusty, pyritic schist.

Unit 4: Flinton Group Metasedimentary Rocks

A small area of metawacke (quartz-feldspar-amphibole-biotite-garnet) was mapped north of Highway 7 in the southern part of the study area. These metasediments are in contact with tholeiitic basalt to the north and granodiorite of the Elzevir Batholith to the east.

Unit 5: Felsic Intrusive Rocks

Traverses included the metavolcanic-intrusive rock contacts where possible, but generally did not extend more than 100 m into the intrusions. Three major intrusive bodies occur in the study area:

1. the Elzevir Batholith: leucocratic granodiorite, locally with narrow, white, quartz veins, and a local, marginal dioritic phase
2. the Mount Moriah Syenite: coarse-grained, pink, biotite-hornblende syenite, and
3. the Caniff Lake Pluton: leucocratic granodiorite, similar to the Elzevir Batholith.

Unit 6: Black River Limestone

A small outlier of Paleozoic rock near the Village of Cooper in Madoc Township was not mapped during the field survey. These rocks were, however, mapped by D.A. Williams (Geologist, Ontario Ministry of Northern Development and Mines, Tweed) during 1987. Williams (personal communication, 1987) described them as green, calcareous feldspathic quartz sandstone of the Shadow Lake Formation of the Black River Group. Thin interbeds of microcrystalline limestone also occur in the section, which has an estimated thickness of about 20 m.

The Paleozoic rocks overlie part of the komatiitic volcanic sequence in Madoc Township. A zone of talc, exposed at the northern edge, and a zone of serpentine, exposed at the southern edge, suggest that a zone of talc-serpentine alteration may be continuous beneath the outlier.

STRUCTURAL GEOLOGY

The metavolcanic rocks in the map area generally strike parallel to, and dip steeply away from, the Elzevir Batholith. Locally, the rocks are intensely folded and sheared; shearing is most common in talc-chlorite-altered komatiites.

Two prominent fault systems (Figure 048.3) are interpreted to occur in the area based upon 1. topographic lineaments visible on aerial photographs; 2. shear zones; and 3. displaced geological contacts. The first fault system strikes north-northeast to northeast, and is represented by the Black River and Caniff Creek in Grimsthorpe Township, and by numerous smaller creeks within the Elzevir Batholith. The second system strikes northwest and is marked by parts of the Black River south of the Village of Cooper, and by numerous creeks and linear swamps in both metavolcanic and intrusive rocks throughout the map area.

Within the metavolcanic rocks, the most prominent shear zones occur along the fault system that parallels the strike of the metavolcanics. South of the Village of Cooper, the major shear zones strike north-

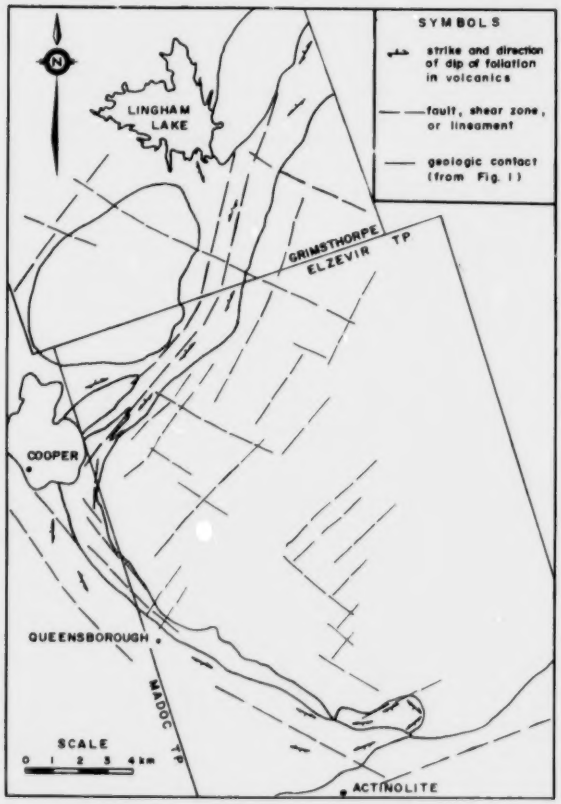


Figure 048.3. *Sketch map showing foliations and prominent lineations in the study area.*

westerly; north of Cooper, they strike northeasterly. These shear zones have developed within the less competent komatiitic rocks and exhibit varying degrees of talc, chlorite, serpentine, and carbonate alteration.

The junction of these two prominent shear directions within the metavolcanic rocks occurs where the komatiites are folded around the westernmost "nose" of the Elzevir Batholith, just east of the Village of Cooper. The occurrence of significant talc-bearing zones in this area (Cooper Area Talc Occurrence, described in Dillon and Barron 1985) may be related to the concentration of structural features in the komatiites east of the Village of Cooper.

Another area in which the occurrence of talc appears to be related to structure is the southeastern end of the komatiite band, between the Flinton Road and the Elzevir Batholith. Here, the metavolcanic rocks have been tightly folded within a horseshoe-shaped embayment in the batholith, and a wide zone of ultramafic komatiites has been extensively altered to talc and serpentine.

No large scale displacement of contacts was observed; the largest contact was a 70 to 100 m right-lateral offset of the fault 400 m north of the Grimsthorpe-Elzevir Township line.

ECONOMIC GEOLOGY

Talc bearing zones in ultramafic komatiites occur throughout the length of a 400 to 2000 m wide band of basaltic and ultramafic komatiites in Elzevir Township, and, to a lesser extent, in thin komatiitic flows within an area of tholeiitic basalts in southern Grimsthorpe Township. Locally, they appear to have economic potential, containing 20 to 80% talc over widths of 5 to 20 m and lengths up to 300 m. These zones are identified on Figure 048.1.

The extent of talc bodies is not known, as the showings consist of scattered outcrops generally leading into low, overburden-covered areas or swamps. Because of their soft and often friable nature, especially where sheared, the talc zones form negative relief features and may be considerably more extensive than is indicated in outcrop. Because magnetite is a common accessory mineral, magnetic surveys should be useful in determining the extent of the talc zones and in locating new zones in areas of low bedrock exposure. All linear bedrock lows within the band of komatiitic basalts should be considered as potentially talc-bearing.

The grade and size of komatiite-hosted talc occurrences in the Tudor Formation compare favourably with those of currently producing Ontario talc mines. The ore zone of the Canada Talc Industries deposit at Madoc averages 5 m in width (up to 18 m) and is 200 m long. It consists of zones of almost pure, white talc and lower grade zones containing dolomite and tremolite. In Penhorwood Township, 75 km west of Timmins, Steetley Industries (Canada) Limited operates an open-pit talc mine in a talc-magnesite-altered ultramafic body near the contact with a granitic-dioritic intrusion. The ore, consisting of talc, magnesite, chlorite, and magnetite, is concentrated by flotation and refined by grinding and air classification to a high quality product used in the paint, paper, plastics, and cosmetics industries (Dillon and Barron 1985). The reported grade of the ore varies from 40% talc (Dillon and Barron 1985) to 28% talc (James Ireland, Geologist, Ontario Ministry of Northern Development and Mines, Timmins, personal communication, 1987).

Studies of the volcanic-hosted talc bodies in the Tudor Formation indicate that a talc product of moderate to high purity could be produced by flotation concentration of the talc-chlorite-dolomite-serpentine-magnetite assemblage. The product has potential application in the paper, paint, plastics, and ceramics industries (Dillon and Barron 1985).

SUMMARY

A series of ultramafic komatiites, komatiitic basalts, and tholeiitic basalts has been identified within the previously undifferentiated mafic volcanic rocks of the Tudor Formation in Elzevir, Madoc, and Grimsthorpe Townships.

Ultramafic rocks within the komatiitic sequence along the western margin of the Elzevir Batholith have been largely altered to talc-chlorite-serpentine-carbonate-magnetite assemblages. Local talc-rich zones appear to have economic potential as low-

grade talc ores which could be refined by flotation to a high-purity product.

Magnetic surveys may be useful in delineating known talc zones and in locating new zones.

Additional work in the form of diamond drilling and bulk sample testing is required to evaluate tonnage and grade potential and reaction to beneficiation processes.

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049. Wollastonite Occurrences Associated with the Deloro Pluton, Marmora and Madoc Townships, Southeastern Ontario

Alistair MacKinnon[1] and P.W. Kingston[2]

[1]Geologist, Ontario Ministry of Northern Development and Mines, Tweed.

[2]Resident Geologist, Ontario Ministry of Northern Development and Mines, Tweed.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

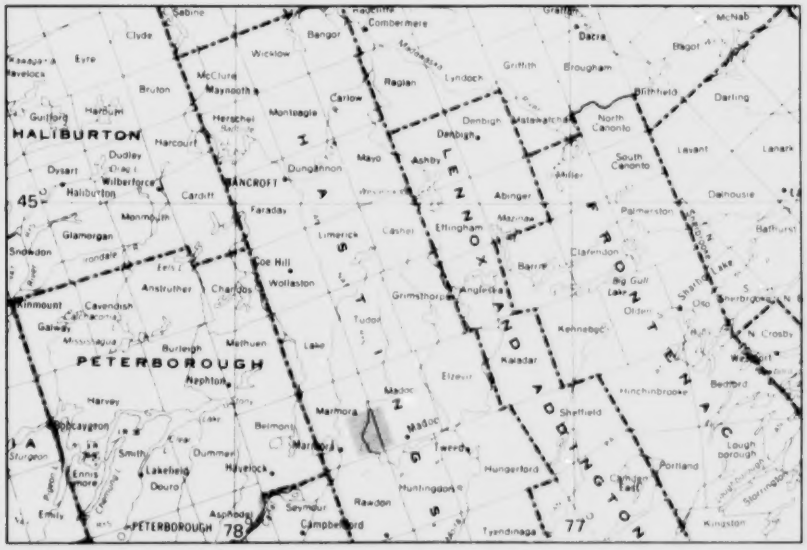
This report presents the results of field work carried out in 1987, which was performed to increase the knowledge of occurrences of wollastonite, discovered in 1986 (MacKinnon 1986; MacKinnon *et al.* 1987), in Marmora Township, southeastern Ontario. Field work in 1987 comprised reconnaissance mapping at a scale of 1:10 000 to identify wollastonite occurrences in the study area, followed by more detailed mapping of occurrences considered to have good potential for development. The preliminary reconnaissance of an arcuate area, 1.0 to 1.5 km wide and extending 10 km along the western margin of the Deloro Pluton in Marmora and Madoc Townships, identified several previously unknown occurrences of wollastonite in calcitic marbles and skarn zones adjacent to the Deloro Pluton and its satellite plutons. The wollastonite is considered to have been produced by the reaction of siliceous fluids, emanating from the felsic intrusion, with calcite in the marble.

Wollastonite is used in a broad spectrum of products such as fillers in plastics, paints, and ceramics; insulating materials; sealants, resins, and bonded adhesives; and as an extender to replace nonfibrous materials and asbestos (Sargent 1972; Choate 1978; Smith 1981; Power 1986).

Canada does not presently produce wollastonite, although several occurrences are currently under investigation in Ontario, British Columbia, Quebec, and Nova Scotia. World demand is largely met by production from the United States, Finland, Mexico, and India. The United States provides the majority (66 percent) of this production (Smith 1981; Power 1986). Global demand for wollastonite is expected to grow at an annual rate of 10 percent (Plumpton *et al.* 1987).

PREVIOUS WORK

Geological mapping in the study area has been done by Wilson (1940, 1:63 360 scale) and Bartlett and Moore (1983, 1:15 840 scale). In addition, the area is included in compilation maps by Hewitt and Satterly (1957), Lumbers (1964), Springer (1978), and Kingston *et al.* (1985). The Paleozoic rocks of the area have been mapped by Carson (1980, 1:50 000 scale) and are currently being investigated by D.A. Williams (Geologist, Ontario Ministry of Northern Development and Mines, personal communication, 1987) at the same scale. Detailed studies of the Deloro Pluton have been made by Saha (1959), Kuehnbaum (1973), Wu (1984), Wu and Kerrich (1986), and Abdel-Rahman and Martin (1987).



LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

GENERAL GEOLOGY

The study area is situated near the southwestern boundary of the Central Metasedimentary Belt of the Grenville Province (Wynne-Edwards 1972), and is underlain by metavolcanic, carbonate, and clastic metasedimentary rocks of the Grenville Supergroup. The stratigraphic succession in Marmora Township youngs from north to south, with dark grey-green, homogeneous, fine-grained amphibolites of volcanic origin being the oldest lithology. These are succeeded to the south by quartzofeldspathic clastic metasediments and intercalated, fine, pyritic biotite schists, which are in turn succeeded by impure to pure carbonate metasediments (Bartlett and Moore 1980). The metasediments, of Grenvillian age, are intruded by mafic to intermediate plutonic rocks and their more felsic derivatives.

Unconformably overlying the Precambrian rocks are Middle Ordovician sedimentary rocks of the Shadow Lake, Gull River, and Bobcaygeon Formations.

METAMORPHISM AND STRUCTURAL GEOLOGY

The regional metamorphic grade of the Precambrian rocks in the study area is middle greenschist facies. The area is within a region of low metamorphic grade, centred around the Village of Millbridge, known as the Hastings Basin (Hewitt 1956).

The emplacement of mafic to intermediate intrusive rocks and their younger, felsic derivatives during a regional plutonic event produced metamorphic thermal aureoles of varying widths. The present study investigated an arcuate zone along the western margin of the Deloro syenite-granite complex. Here, the metamorphic grade in the contact aureole is interpreted to have reached amphibolite-hornfels facies, based on the presence of wollastonite and diopside within the aureole (MacKinnon *et al.* 1987).

The Precambrian metasediments were subjected to several periods of deformation and metamorphism, resulting in a southeasterly dipping structural fabric, except near plutonic bodies, around which this fabric appears to be wrapped.

The predominant structural feature of the area is a fault system which extends south from the community of Malone to Thomasburg, some 16 km southeast of the Town of Madoc (D.A. Williams, Geologist, Ontario Ministry of Northern Development and Mines, Tweed, personal communication, 1987). Along the western contact of the Deloro Pluton, there is a north-trending fracture system, which controls auriferous arsenopyrite-quartz veins and minor intrusions, and a younger, east- to southeast-trending fracture system containing amphibolite dikes and postmetamorphic barite-fluorite veins.

DESCRIPTION OF MAP UNITS

The locations of the properties described in this report are shown on Figure 049.1.

Clastic metasediments (map unit 1) consist mainly of strongly foliated schists. They crop out along the faulted northern margin of the Deloro Pluton, and are locally interbedded with carbonate metasediments (map unit 2).

The carbonate metasediments (map unit 2) within the study area vary in composition from calcitic-dolomitic to calcitic marble, with most being calcitic. Considerable variation in colour, mineralogy, and texture can be observed in this unit. The marbles vary from a fine- to medium-grained, white calcitic marble, which may contain accessory quartz, serpentine, hematite, and sulphide mineralization, through a foliated, brecciated, and banded, grey and white calcitic marble, to white, dolomitic marble with calcite, tremolite, and brucite as accessory minerals. Light green to grey, aphanitic, serpentinized calcitic marble is commonly present close to the wollastonite zones. This serpentinized marble contains accessory tremolite, diopside, dolomite, and quartz.

Fine- to coarse-grained, gabbroic to dioritic intrusive rocks (map unit 3) occur along the southwestern margin of the Deloro Pluton and as inclusions within the pluton.

Felsic intrusive rocks (map unit 4) in the map area include the Deloro syenite-granite complex, the Malone syenite, and a small, highly sheared, granitic satellite stock of the Deloro complex. The Deloro syenite-granite complex is exposed in a crescent-shaped area of approximately 35 km^2 in Marmora and Madoc Townships. In general, it consists of massive, medium- to coarse-grained syenite and hornblende syenite, and gradually becomes more siliceous toward its centre. It lacks a deformation fabric, and contains inclusions of gabbro, diabase, and volcanic rocks (Abdel-Rahman and Martin 1987).

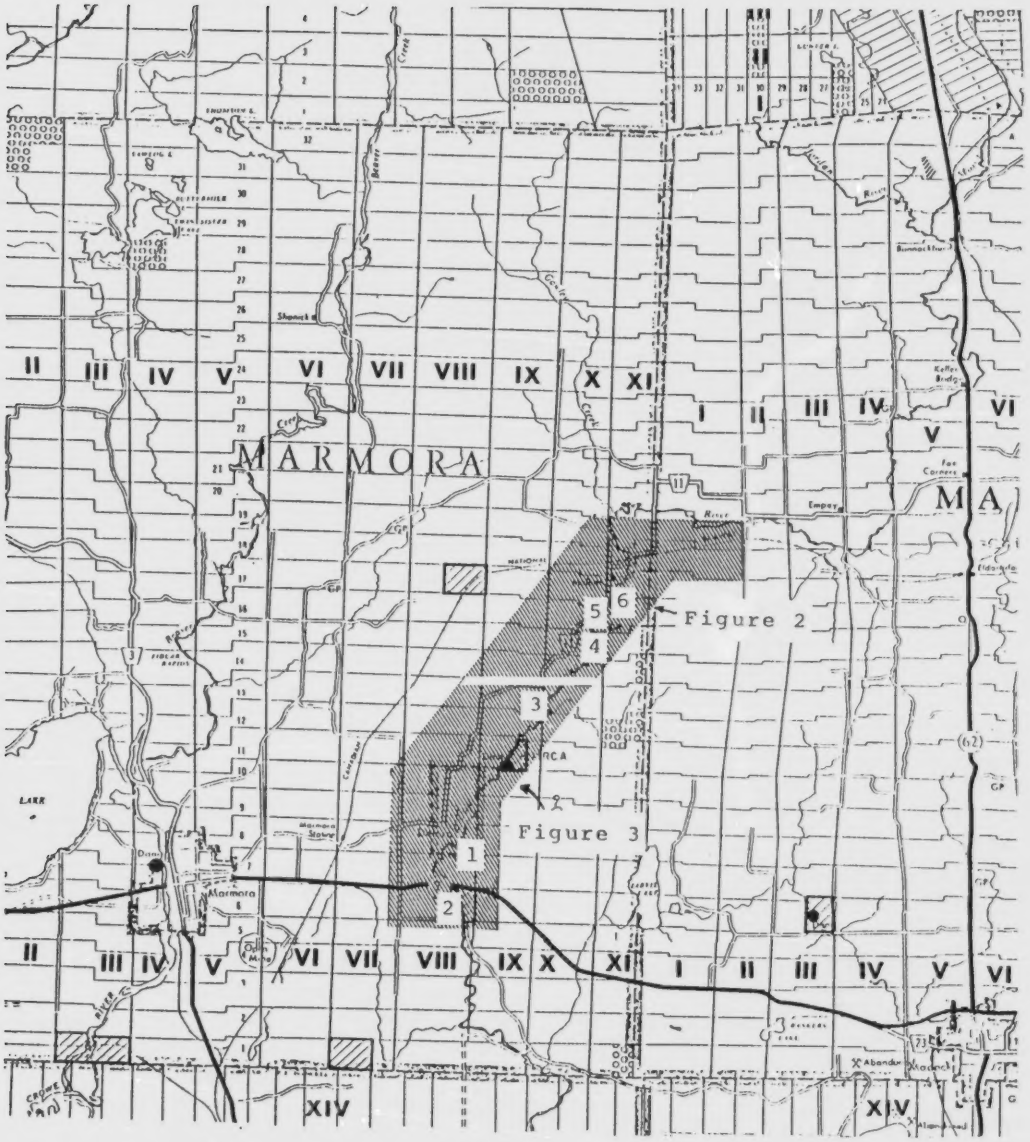
The Shadow Lake Formation (map unit 5) is a fine-grained to conglomeratic, maroon to green, calcareous, feldspathic quartz sandstone, which is thinly to medium bedded. Quartz clasts up to 1.5 cm in diameter can be observed in some localities. The formation is generally 15 to 25 cm thick in exposed areas.

The Gull River Formation (map unit 6) is exposed in concession VIII, lots 10 and 11, Marmora Township, and in a small quarry at the northern end of the community of Deloro. It is a brownish-grey, fine- to medium-grained, microcrystalline limestone with abundant shaley partings (D.A. Williams, Geologist, Ontario Ministry of Northern Development and Mines, Tweed, personal communication, 1987).

The Bobcaygeon Formation (map unit 7) is a brownish grey, thinly to massively bedded, microcrystalline limestone with undulating shaley partings. It is exposed along a hillside and hilltop in concession VIII, lots 10 and 11, Marmora Township, in a small, down-faulted wedge at the western edge of the study area.

DESCRIPTION OF WOLLASTONITE OCCURRENCES

Zones where wollastonite is known to occur in the study area are shown on Figures 049.2 and 049.3. Diagram size prevents identification of different wollastonite assemblages; several of the occurrences are briefly described below.



Miles 1 0 1 2 3 4 5 6 Miles

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L E G E N D

1. Blackhawk - Cominco Property
2. Deloro West Zone
3. Rahm Property
4. Moira River Conservation Authority Property
5. Kelly-Czerewko Property
6. Bonter Property

Figure 049.1. *Location map of the study area and wollastonite properties.*

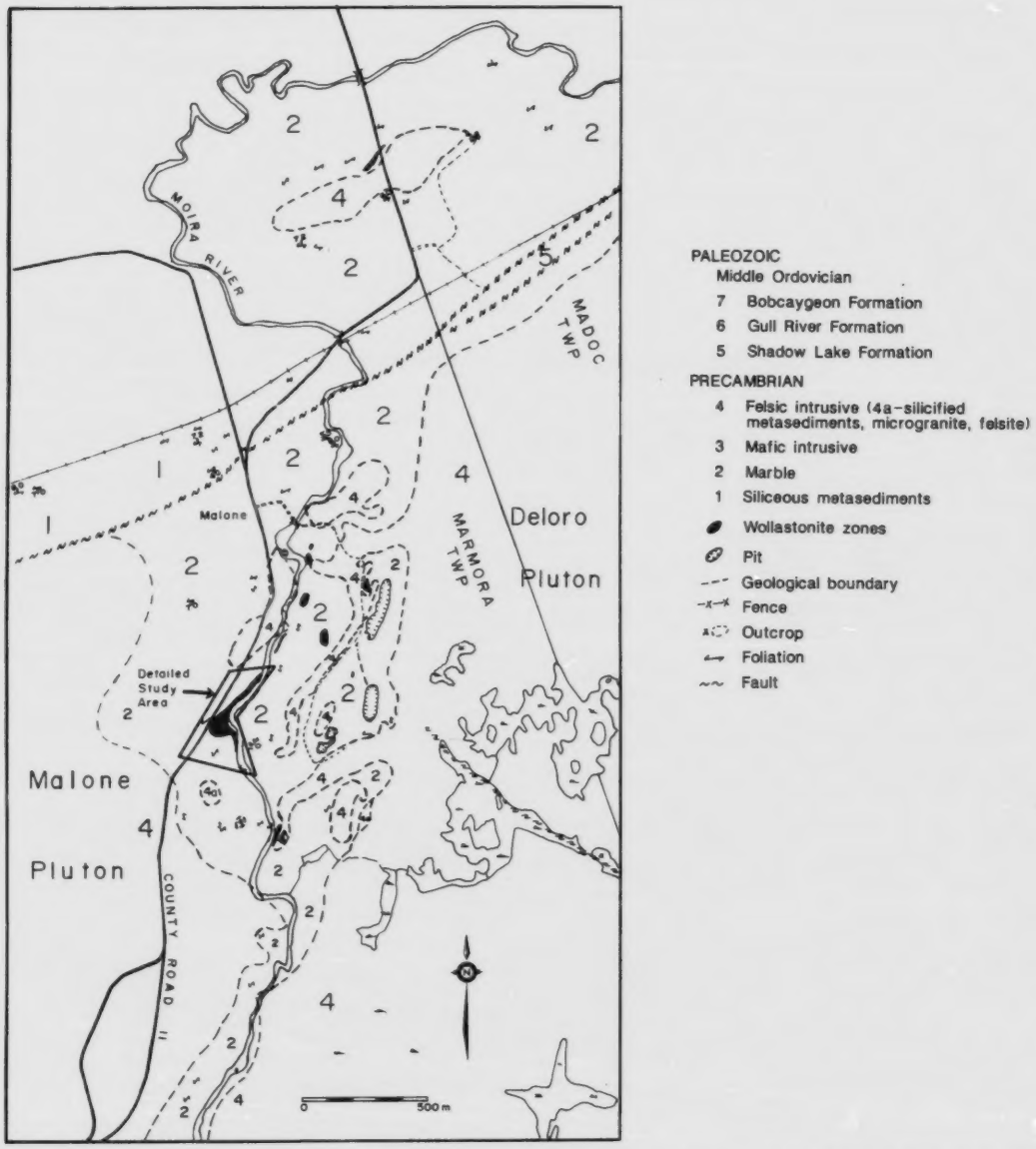


Figure 049.2. *Geology of the northern portion of the study area, and location of the detailed study area.*

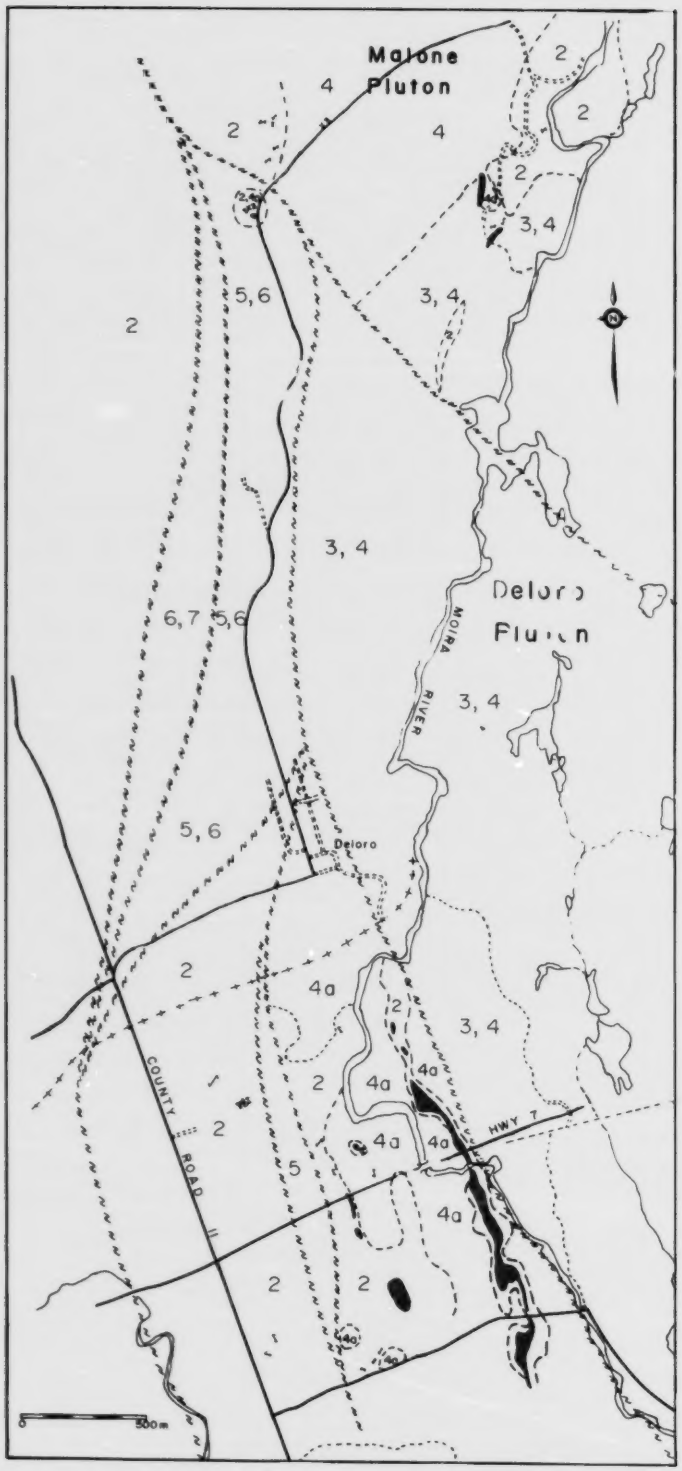
BLACK HAWK MINING INCORPORATED-COMINCO LIMITED PROPERTY

The Black Hawk Mining Incorporated-Cominco Limited Property is located on lots 5, 6, 7, and 8, concession VIII, Marmora Township, approximately 5 km east of the Town of Marmora. Access to the property is via Highway 7 and from the old Madoc-Marmora Road.

Exploration activity on the property during the Summer of 1987 included geological mapping, stripping, trenching, and diamond drilling. At the time of writing, a two-acre area had been stripped and blasted north of Highway 7 in order to obtain a bulk sample for beneficiation testing.

Mineralization occurs in a northwest-trending zone of calcitic marble, which exhibits little or no internal structure. However, if the zone is consistent with the adjacent metasediments, dips of 45° to 50°E can be expected. The zone extends almost continuously for 1200 m along strike, varying in width from a few to 100 m. This variation results in a pinch and swell or lens-like appearance. Preliminary testing by Kretschmar (1986) indicated that the deposit contained at least 2 million tonnes grading 40 percent wollastonite; visual estimates of grade and tonnage by the authors are similar.

The host marble is fine to medium grained, and white to light green in colour. It consists predominantly of wollastonite and calcite, with minor amounts



PALEOZOIC
Middle Ordovician
7 Bobcaygeon Formation
6 Gull River Formation
5 Shadow Lake Formation
PRECAMBRIAN
4 Felsic intrusive (4a-silicified metasediments, microgranite, felsite)
3 Mafic intrusive
2 Marble
1 Siliceous metasediments
Wollastonite zones
Pit
Geological boundary
Fence
Outcrop
Foliation
Fault

Figure 049.3. *Geology of the southern portion of the study area.*

of diopside and quartz (up to 1 percent). Trace amounts of tremolite, talc, mica, chlorite, and fine-grained, disseminated pyrite also were identified in some samples (MacKinnnon *et al.* 1987).

The wollastonite occurs in nodular aggregates, 1 to 30 cm in diameter, or as blades and fibres in a fine- to medium-grained calcitic matrix. Individual blades up to 6 cm long were noted in the southern portion of the property.

The weathered surface is unique, and quite useful in indicating the presence of wollastonite in the rock. This surface is a mottled grey or black in colour, and has a pitted appearance, with the calcite standing out in relief and the wollastonite weathering low. However, this relationship is reversed, as might be expected, where overburden has prevented grain disintegration by weathering. This feature was evident in the stripped area north of Highway 7.

In outcrops that are highly weathered and contain a high percentage of wollastonite, the wollastonite is creamy brown in colour, has a friable texture, and frequently fractures into fan-shaped fragments. These weathering features are apparent not only at this property but at most, if not all, of the wollastonite occurrences in the area.

Both felsic and mafic dikes intrude the wollastonite zone. Several dikes are particularly well exposed in the stripped area north of Highway 7, where two intersecting mafic dikes were observed. One strikes approximately parallel to the wollastonite zone and may, in fact, be an extension of the dike observed at the highway. The second strikes across the mineralized zone. The dikes vary from 1 to 2 m in width and appear to be approximately vertically dipping.

Fine-grained, dark green to grey, serpentinized calcitic marble crops out adjacent to the wollastonite zone. This unit is composed of calcite and serpentine, with minor tremolite, dolomite, and diopside. However, in an outcrop on the northern side of Highway 7, the marble is a white, banded, and brecciated calcitic marble, which locally contains barite.

Map unit 4a (silicified metasediments, microgranite, and felsite) is in contact with this marble and, in some places, with the wollastonite zone itself. Unit 4a is an aphanitic, siliceous rock, composed of quartz and accessory epidote, feldspar, sulphide minerals, tremolite, and mica. It varies from massive to banded, in places brecciated, and from a dark grey to green and brown mottled colour. Weathered surfaces vary in colour from white to orange.

The Deloro Pluton and its attendant gabbroic to dioritic phases occur along the eastern edge of the property.

KELLY-CZEREWKO PROPERTY

This occurrence is located on lot 16, concession X, in Marmora Township, approximately 5 km north of the community of Deloro. Figure 049.4 is a detailed geological map of the property.

The property is underlain by massive to foliated, white to grey, calcitic marbles and siliceous, wollastonite-bearing marbles. A magnetite-bearing skarn containing massive garnet and diopside is exposed in an open cut which is 4 m wide, 18 m long, and 1 to 4 m deep. Magnetite was mined here in the 19th century.

Wollastonite mineralization occurs as three distinct types: a) a very siliceous variety (map unit 2c, Figure 049.4) consisting of varying proportions of wollastonite, quartz, calcite, and diopside; b) in a calcitic marble (map unit 2d, Figure 049.4), similar to the Black Hawk-Cominco Property but containing more calc-silicates; and c) associated with a metasomatic iron occurrences (map unit 1, Figure 049.4). Most of the mineralization is of the first type; consisting of coarse-grained, prismatic wollastonite and quartz, with lesser amounts of calcite and diopside. The second type of mineralization was identified only in a 0.5 m wide band of calcitic marble, exposed in a roadcut on the western side of county road 11. Here, the wollastonite occurs as elongate aggregates in a foliated, fine- to medium-grained, white, calcitic marble, which contains accessory quartz, pyrite, and tremolite. The third mineralization type was only observed in the wall of an open cut on the property. The hanging wall of the massive magnetite unit contains mainly massive quartz, with lesser amounts of coarse-grained wollastonite, massive garnet, and diopside and fine- to medium-grained calcite.

Other known metasomatic iron occurrences along the margin of the Deloro Pluton may, therefore, prove to be useful targets for wollastonite.

RAHN PROPERTY

This showing is located in the northeastern corner of lot 12 and the southeastern corner of lot 13, concession IX, Marmora Township, approximately 5.5 km northeast of the community of Deloro. The property is accessible by a trail which connects with county road 11.

The property is underlain by carbonate metasediments and younger mafic to felsic intrusive rocks. The metasediments consist of fine- to medium-grained, white to dark green, calcitic marbles, which may contain serpentine, tremolite, quartz, hematite, and sulphide mineralization, and white, fine-grained, calcitic dolomite, with accessory brucite, serpentine and tremolite.

Massive, medium- to coarse-grained syenite, hornblende syenite (in places porphyritic) and microgranite (?) occur along the western and southern boundaries of the map area. Preliminary mapping in 1987 has identified two lens-like pods containing wollastonite. The southern pod is 15 m wide and 90 m long, and contains up to 50 percent wollastonite. The host marble is white, fine to medium grained, and contains wollastonite, calcite, diopside, and minor quartz. Massive garnet was identified in the rubble near a small pit in the pod. The northern pod is 30 m wide and 125 m long, and is more siliceous than the southern pod. Wollastonite content is more variable than in the southern pod: wollastonite is fine to coarse grained, with both grain size and amount of wollastonite decreasing to the south within the pod.

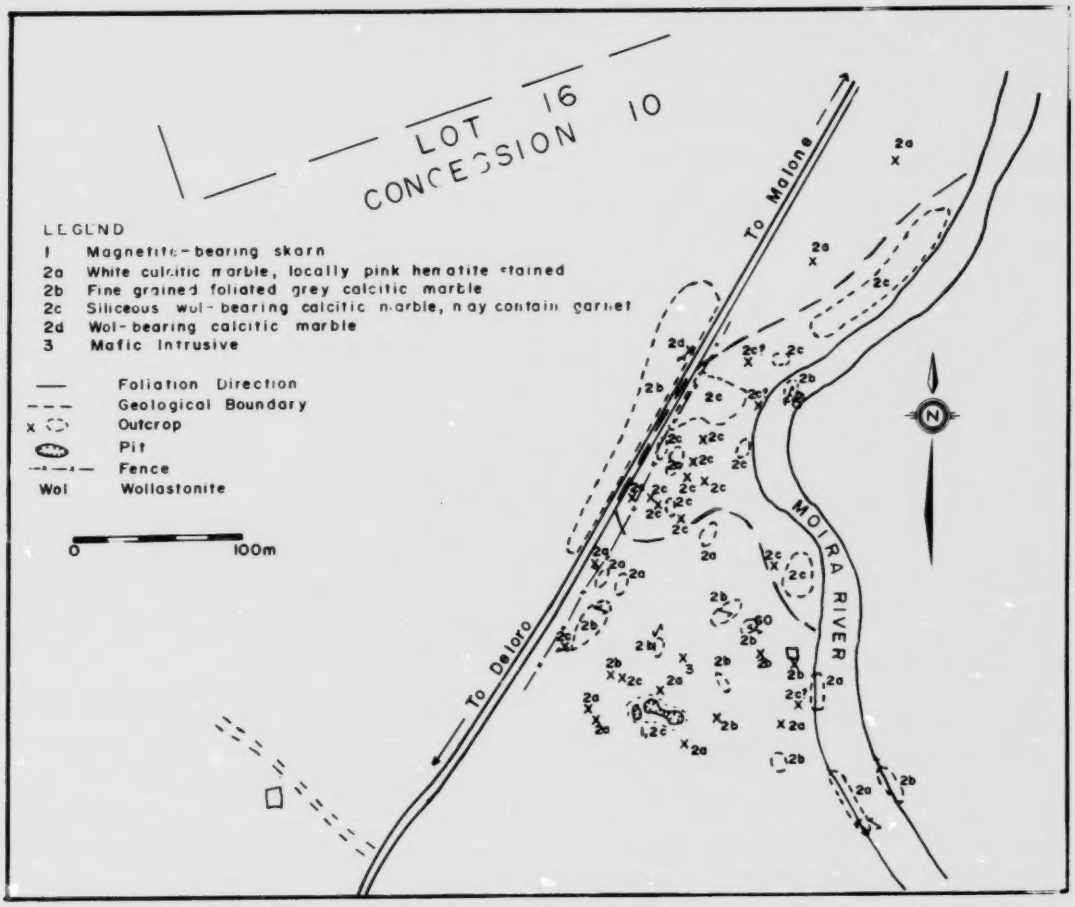


Figure 049.4. *Geological sketch map of the detailed study area.*

BONTER PROPERTY

This showing is located in the northwestern corner of lot 16 and the southwestern corner of lot 17, concession XI, and the northwestern corner of lot 16, concession X, Marmora Township, southeast of the community of Malone. Access to the property is via a dirt road running east across the Moira River. The property is owned by R. Gulliet, who has recently applied for a quarry permit to extract high calcium material from the site.

The geology and mineralogy of the wollastonite zones here are similar to those of the previously described occurrences. Both siliceous and non-siliceous varieties of wollastonite mineralization are present.

Although significant concentrations of wollastonite have been identified on the property, detailed mapping and stripping are required to enable reliable correlation of the mineralized zones.

DELORO WEST ZONE

The Deloro west zone is located on lots 6 and 7, concession VIII, Marmora Township, approximately 4.5 km east of the Town of Marmora. Access to the property is via Highway 7 and the old Madoc-Marmora road.

The geology and mineralization at the Deloro west zone are similar to those of the Black Hawk-Cominco Property, but the mineralization is not as extensive, and its width is highly variable, even over short distances. For example, in the roadcut on the northern side of Highway 7, the wollastonite zone is only 0.7 m wide, while on the southern side, there are two separate bands of wollastonite-bearing rock, 5.1 and 1.1 m in width. The two bands appear to strike 004°, and dip 36°E and 26° to 36°E, respectively. Repetition of the metasediments at this locality suggests folding, and the two bands may be one and the same. Some 150 m south of Highway 7 on lot 6, the wollastonite-bearing zone appears to dip 10° to 20°E, and plunges 21°N.

MOIRA RIVER CONSERVATION AUTHORITY PROPERTY

Wollastonite-bearing rocks crop out over a 10 by 75 m area by the eastern shore of the Moira River on lot 15, concession X, Marmora Township, south of the Bonter Property. One end of this outcrop is massive, and the other end is strongly foliated (foliation strikes 043° and dips 67°E). The rock appears to be at least 50 percent wollastonite; minor quartz is present at the southern end of the outcrop.

OTHER OCCURRENCES

Wollastonite was also identified in a small Precambrian inlier on lot 13, concession IX, Marmora Township, and on the Noranda Incorporated Property on lot 19, concession XI, Marmora Township and lot 19, concession I, Madoc Township. At the latter occurrence, wollastonite is associated with a small, highly sheared, auriferous satellite pluton of the Deloro Pluton.

SUMMARY

Field work conducted in 1987 has greatly expanded the knowledge of wollastonite occurrences in Marmora and Madoc Townships:

1. The wollastonite occurrences examined all occur within an area of thermal metamorphism adjacent to felsic plutons. These high-temperature mineral assemblages are preserved in the Hastings Basin, an area of greenschist facies regional metamorphic grade.
2. The wollastonite mineralization is hosted by white, fine- to medium-grained, calcitic marble. The weathered surface of the host rock typically exhibits a characteristic pitted texture, which provides a quick and accurate preliminary identification of the presence of wollastonite.
3. Field observations suggest that the wollastonite content of the mineralized zones varies from 20 to over 50 percent.
4. Several exploration targets were identified during the field work. Stripping, and detailed geological mapping, are required to accurately evaluate these targets.

ACKNOWLEDGMENTS

The authors wish to thank D.A. Williams (Geologist, Ontario Ministry of Northern Development and Mines, Tweed) for his structural interpretation of the study area, and his informative discussions on the geology of the Paleozoic rocks in the area. We also wish to thank Noranda Incorporated for permitting examination of diamond drill core from their property, and B. Sakrison (Geologist, Cominco American Limited) for permitting access to their property. S. Cole was a capable field assistant.

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050. Geological and Geophysical Studies of the Madoc Fluorite Area, Southern Ontario

L.G.D. Thompson[1] and D.A. Williams[2]

[1]Geophysicist, Ontario Ministry of Northern Development and Mines, Tweed.

[2]Geologist, Ontario Ministry of Northern Development and Mines, Tweed.

The geological work done in this project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

The Madoc fluorite area is located in Hastings County, southern Ontario, 190 km northeast of Toronto. Field work was carried out in 1987 in parts of Marmora, Madoc, Elzevir, Rawdon, Huntingdon, and Hungerford Townships.

The geological work reported here is a continuation of the 1986 program (Williams and Thompson 1986). The purpose of the field work was to locate faults in the Madoc fluorite area and define their vertical displacement, since a knowledge of the fault system in the area could be expected to provide a better understanding of vein localization, thereby increasing exploration potential.

The geophysical work done during 1987 was a continuation of a project initiated during 1984-85 by Thompson (1986) and later incorporated into the 1986 project conducted by Williams and Thompson (1986). The geophysical surveys aided in the geological mapping by locating faults and identifying different rock types in areas where the bedrock is covered by overburden. Because geophysical anomalies are associated with the fault system, these surveys also contributed to the identification of areas with a high potential to contain fluorite deposits.

GEOLOGICAL STUDIES

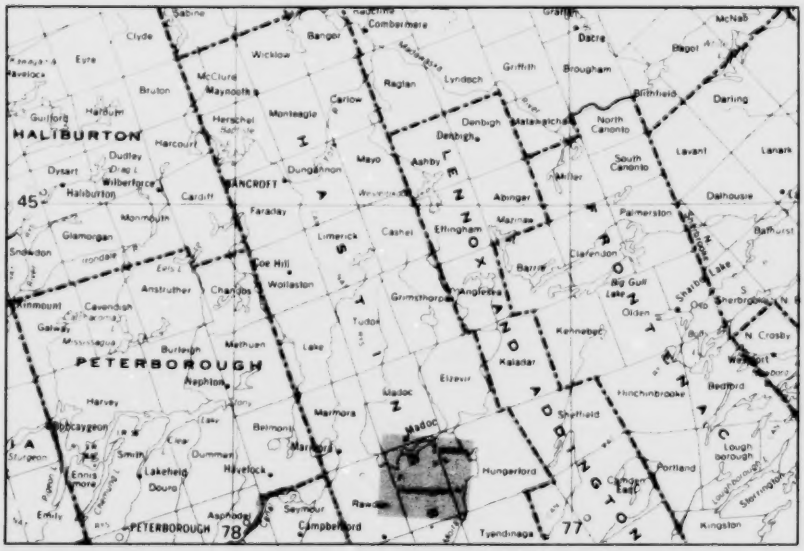
Geological mapping included the examination of outcrops of Paleozoic rocks and the location of exposures of Precambrian rocks. The distribution of both Precambrian and Paleozoic units, the interpreted locations of normal faults, and the locations of fluorite-bearing veins in the study area are shown in Figure 050.1.

STRATIGRAPHY

Both deformed Precambrian metamorphic and igneous rocks and gently dipping Paleozoic sedimentary rocks are extensively exposed in the Madoc area (Figure 050.1). The Paleozoic rocks are of Middle Ordovician age and consist of the Shadow Lake, Gull River, Bobcaygeon, and Verulam Formations, in ascending order. Stratigraphic control is provided by an exposure in the abandoned open pit iron mine at Marmora in which this entire Paleozoic sequence, except the Verulam Formation, is exposed. This stratigraphy, as exposed at Marmora, is summarized in Table 050.1.

STRUCTURAL GEOLOGY

Normal faults in the Madoc area (Figure 050.1) strike parallel to rift zones in the region (Ottawa Valley, Timiskaming Valley, Champlain Valley, and southern Great Lakes). Fault traces are normally gently curved,



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

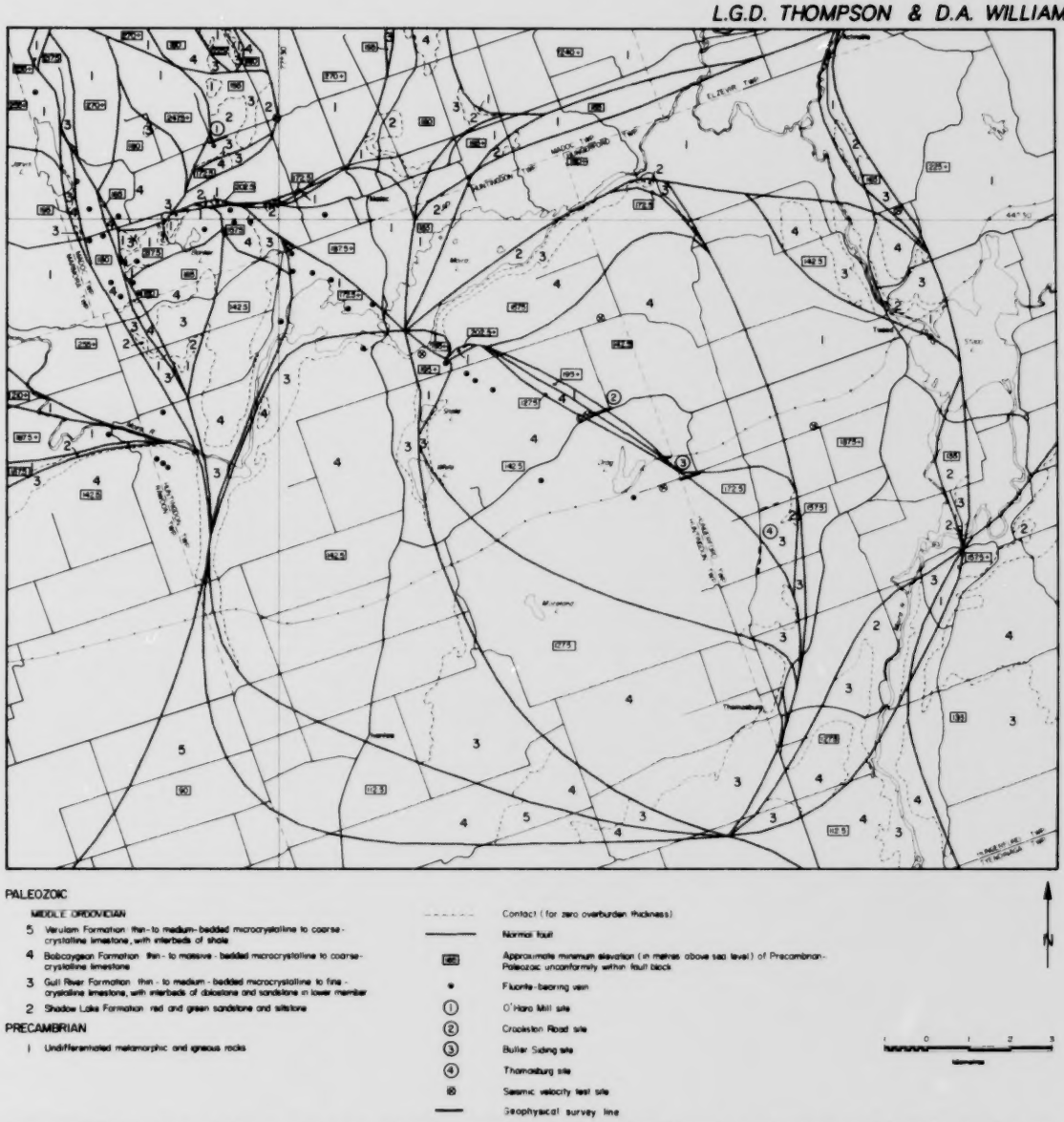


Figure 050.1. *Map of the study area, showing Precambrian and Paleozoic rock units and locations of normal faults, fluorite-bearing veins, and geophysical survey sites.*

but may be distinctly curved in the vicinity of fault junctions. In this study, the approximate minimum elevation of the Precambrian-Paleozoic contact was determined, in multiples of 7.5 m, for each fault block. Elevations of at least 270 m exist in the northern part of the area, and elevations as low as 90 m occur in the southern part of the area. Figure 050.1 shows only faults with at least 15 m vertical displacement; displacements of more than 90 m have been detected. The susceptibility of faults to weathering has resulted in many fault-controlled, linear, topographic lows in the study area; the most notable lows include segments of the Moira River, including Moira Lake. Within any one fault block, the elevation of the contact between two stratigraphic units generally varies by no more than a few metres. Bedding dips relatively steeply away from Precambrian highs, the vicinities of which are characterized by an absence of the lowermost Paleozoic units. A notable series of Precambrian highs extends north-northeastward from Banker Lake, 5 km west of the town of Madoc, and consists of resistant, mafic metavolcanics.

ECONOMIC GEOLOGY

Fluorite-bearing veins in the Madoc area (Figure 050.1) are southeasterly striking fracture fillings with a common left-lateral, *en echelon* mode of occurrence. The veins are located next to faults within a southeasterly striking fault zone which is approximately 10 km wide and extends from Malone, 12 km northwest of the town of Madoc and outside

TABLE 050.1. STRATIGRAPHY OF PALEOZOIC ROCKS AT MARMORA, AS MEASURED AT THE OPEN PIT IRON MINE.

Formation	Lithology	Thickness
Verulam	thin to medium bedded, microcrystalline to coarse crystalline limestone	not exposed at Marmora
Bobcaygeon		
Upper Member	thin to massive bedded, microcrystalline to medium crystalline limestone	2.60 m
Lower Member	thin to massive bedded, microcrystalline to fine crystalline limestone	13.70 m
Gull River		
Upper Member	thin to medium bedded, microcrystalline to fine crystalline limestone	7.19 m
Lower Member		
Upper Submember	limestone, dolostone and sandstone	11.75 m
Lower Submember	red and green dolomitic limestone, dolostone and sandstone	8.09 m
Shadow Lake	red and green sandstone and siltstone	6.27 m

the area of Figure 050.1, to Thomasburg, 16 km southeast of Madoc. The deposits that have historically been of most economic significance are located close to the junctions between faults.

Undiscovered veins can be expected to exist within the fault zone. In addition to geophysical methods, geochemistry is an effective exploration tool. Lalonde (1974) concluded that the fluorine content of surface water and groundwater is most useful for reconnaissance surveys, and that fluorine, barium, and zinc contents of soils are most useful for detailed surveys. A groundwater fluorine map showed many anomalies in addition to those associated with known fluorite mineralization (Lalonde 1974, p.22-23); the most anomalous sample, from the Jarvis Lake area west of the town of Madoc, contained 1800 parts per billion fluorine.

GEOPHYSICAL STUDIES

In 1987, geophysical surveys were done at the O'Hara Mill site in Madoc Township, the Crookston Road site in Huntingdon Township, the Buller Siding site in Hungerford Township, and the area immediately north of Thomasburg in Hungerford Township (Figure 050.1). Seismic refraction surveys were performed to aid in the location of major faults and in the identification of different rock types in overburden-covered areas of fault blocks. Magnetic surveys along the seismic survey lines were done to support the seismic results, particularly where Paleozoic limestone is faulted against Precambrian mafic rocks. Resistivity/conductivity surveys were done to locate any conducting zone associated with a fault that might indicate the presence of a fluorite vein or other mineralization. A scintillometer was used to examine the remaining surface vein cuts at several fluorite mine sites for gamma radiation. Alpha meter surveys were done in anticipation that some radioactive mineral is present in the fluorite veins, and that radon gas is percolating through the overburden above them.

SEISMIC SURVEYS

To aid in identifying different subsurface rock types, seismic velocities of several types of Precambrian and Paleozoic rocks in the Kingston-Marmora area have been measured since 1985. These reference seismic velocities are given in Table 050.2. Locations of some of the test sites are included on Figure 050.1.

In 1987, seismic refraction surveys were done with a computer-aided portable seismograph system, previously described by Thompson (1987). This system features a Geometrics 12-channel ES-1225 portable seismograph linked to a portable computer. The seismic data for a 12-channel record are stored directly onto a computer disk for further processing.

Along a survey line, continuous forward and reverse refraction spreads, 52 m in length with geophones at 4 m intervals, gave a profile of bedrock depths. At other locations, single spreads gave spot depth measurements. The seismic velocities were used to identify subsurface materials.

At the O'Hara Mill site, the previous seismic survey line (Williams and Thompson 1986) was extended eastward along the 5-6 sideroad to a distance of 1320 m (Figure 050.1). In addition, two spreads were shot on the Concession IV road. One was from about 110 m to 162 m south of the 5-6 sideroad, and the second was from about 80 m to 132 m north of the 5-6 sideroad (Figure 050.1).

At the Crookston Road site (County Road 38), the previous survey line (Thompson 1986) was extended eastward along the Crookston Road to a distance of 500 m (Figure 050.1), and several spreads were shot in a south-north direction in fields on the north side of the road.

North of Thomasburg, three spreads were shot on the old Thomasburg road, just north of the Concession VI road (Figure 050.1), and two spreads were shot on the Concession VIII road just east of the old Thomasburg road (Figure 050.1).

MAGNETIC SURVEYS

Total field magnetic surveys using a Geometrics Model G 816 Proton Magnetometer were done along the seismic survey lines at the Buller Siding (Concession IX road) site, the Crookston Road site, and the O'Hara Mill site (including a south-north survey line along the Concession IV road). Readings were taken at 4 m intervals at geophone locations.

TABLE 050.2. REFERENCE SEISMIC VELOCITIES OF ROCKS IN THE KINGSTON-MARMORA AREA.

Location Lot	Conc.	Twp	Rock Type	Velocity (m/s)	Comments
12	11	Hungerford	PC Granite Gneiss	4825	S side Conc. 12
12	12	Huntingdon	PC Granite Gneiss	4710	NW Noyes Mine
Abandoned RR bed					
6	9	Hungerford	PC Granite Gneiss	3145	Pegmatitic
2	4	Madoc	PC Phyllite	5195	Old Hwy 7 cut
5	5	Madoc	PC Mafic Volcanic	5825	Mapped as amphibolite
O'Hara Mill Road					
1	4	Madoc	PC Greywacke	2200-2670	Bailey Mine
N Side Town Line					
19	1	Madoc	PC Black Banded Marble	2625	Igneous bands
E Side Town Line					
19	5	Madoc	PC Black Marble	3600	E of Moira River
S Side Conc. 20					
22	6	Madoc	PC White Marble	4030	Old Quarry
22	6	Madoc	Shadow Lk Sst.	2230	Thick bedded
1	6	Camden	Upper Gull River	5175-5665	Roblindale Quarry Floor
5	5	Kingston	Lower Bobcaygeon	1265-2155	Surface water-eroded blocks
Ont. Hydro Tower					
126 Site, Glenvale			Lower Bobcaygeon	3475-3860	Jointed with sink hole
			Lower Bobcaygeon	4425-6195	Lower layers
19	8	Huntingdon	Lower Bobcaygeon	2080	Surface water-eroded blocks
S Side Conc. 9					
W of Hydro Line			Lower Bobcaygeon	4775	Lower layers
17	10	Huntingdon	Upper/Lower Bobcaygeon Contact	3030	Surface water-eroded blocks
N Side Crookston Road					
18	10	Huntingdon	Upper Bobcaygeon	4570	N Crookston Road
20	12	Huntingdon	Upper Bobcaygeon	4810	N Quin-mo-lac Rd

RESISTIVITY SURVEYS

In the fall of 1986, a resistivity survey using a Scintrex RSP-6 Resistivity Meter was done over the portion of the Buller Siding seismic survey line that had previously been surveyed with a Geonics EM-31 Conductivity Meter (Thompson 1986). The RSP-6 gave greater depth penetration than the EM-31, and was used to investigate further the EM-31 conductivity anomaly at about 160 m on the survey line. In addition, the resistivity measurements confirmed previously measured depths to bedrock. Initially, expanding Wenner spreads were used, with spacings increasing from 4 m to 22 m at 2 m intervals. For profiling, a Wenner spread with 20 m spacing was used. The results of this resistivity survey are included in this report.

RADIOACTIVITY SURVEYS

A scintillometer examination was made of the remaining surface vein open cuts at the McIlroy, Noyes, and Rogers fluorite mines, using a McPhar TV-1A spectrometer. At the McIlroy and Rogers Mines, the background radiation level was about 12 counts per minute (cpm), which is the atmospheric radiation level monitored in Tweed. No radiation anomaly was detected along the whole length of the McIlroy open cut, or in the area to the north. At the Rogers Mine, the background level was also about 12 cpm, but two pockets of altered wall rock gave counts up to 50 cpm. At the Noyes Mine, the background radiation level was higher, at about 20 cpm, probably due to the granitic gneiss country rock being more radioactive. Several places where the wall rock was altered gave higher counts, up to 50 cpm.

Alpha Nuclear alpha meters were used to survey the seismic line at the Buller Siding (Concession IX) site. The first work was done during 1986, but the data were not processed until 1987. In 1987, an additional alpha meter survey line was run along the abandoned railway line just northwest of the Concession IX line (Figure 050.1). This line extended across the extrapolated location of the fault zone identified on the Concession IX road (Thompson 1986). For both survey lines, one alpha meter was left in one location and read daily to give a reference or base station count. Three other meters were placed at 4 m intervals along the survey lines at geophone locations, and read and moved daily (except on weekends). All readings (counts per hour) were corrected

for daily variations recorded by the reference meter. Sections of the Concession IX survey line which gave higher than average readings (about 35 counts per hour) were resurveyed with alpha meters placed at 1 m intervals. No anomalous high counts were noted along the railway survey line, but some were obtained along the Concession IX survey line.

Alpha meter tests were also done at the McIlroy and Noyes Mines to see if any alpha radiation is associated with known fluorite vein sites. At the McIlroy Mine, the meters were placed in a 1 m square grid at the north end of the open cut and also farther west near the access road. Readings were taken daily for several days at each site. The average counts were high in these two areas, at about 115 and 165 counts per hour, respectively. At the Noyes Mine, the meters were placed in a 1 m square grid over the fluorite vein just north of the Number 2 shaft. The average count was high, about 180 counts per hour.

Since very low alpha counts per hour were being measured, it was necessary to establish a criterion for assessing what constituted an anomaly. An *in situ* test of the alpha meters was therefore done at the Drill Core Library, Ontario Ministry of Northern Development and Mines, Tweed, over a period of more than one month. The meters were placed in the ground in a 1 m square grid and read daily, or as frequently as otherwise possible. The meters were also rotated from position to position. The average count was about 105 counts per hour. A statistical error analysis of this large quantity of data showed that the variation in reading between meters at the same location was about ±10 percent. More importantly, the variation or uncertainty in a reading by random placement of any one meter was about ±15 percent. As a safe criterion, it was assumed that an individual reading could have an uncertainty of about ±25 percent. Thus, a count per hour increase of 100 percent or more should be an anomaly of interest.

O'HARA MILL SITE RESULTS

Figure 050.2A shows the seismic and magnetic results from west to east along the 5-6 sideroad survey line, and Figure 050.2B shows the results from south to north along the Concession IV road, perpendicular to the 5-6 sideroad line. The distance shown on the horizontal axis of Figure 050.2A is measured from the end of the 1986 seismic line at this site, which was 840 m long.

The 1986 seismic line ended just east of the Concession IV road. Just west of this road, the results of the 1986 seismic survey show a steady rise in the surface of the Precambrian bedrock, as well as a sudden decrease in bedrock velocity from over 5000 m per second to less than 3500 m per second (Williams and Thompson 1986). The 1987 seismic line shown in Figure 050.2A overlaps this section, and confirms the sudden decrease in Precambrian bedrock velocity. This indicates a distinct change in the type of Precambrian bedrock, from high velocity mafic metavolcanics in the west, to a lower velocity material, perhaps marble (see Table 050.2), in the east. The conclusion is that a fault in the Precambrian bedrock must exist just west of the Concession IV road, as shown on Figure 050.2A.

The Precambrian bedrock profile of Figure 050.2A shows that the low velocity rocks extend over the whole area to the east. This Precambrian surface rises to a peak at about 980 m and then falls away to greater depths further eastward. West of this Precambrian peak, the intermediate layer above the Precambrian surface is till. East of the peak, the till gives way to a layer of Shadow Lake Formation above the Precambrian. The Shadow Lake Formation is identifiable by its very low seismic velocity (less than 3000 m per second; Table 050.2). The presence of the Shadow Lake Formation is established by outcrops in the creek bed shown on Figure 050.2A, and at slightly higher elevations to the east and south.

The magnetic profile in Figure 050.2A is very irregular, but shows a slight anomaly of about 200 gamma over the till, which thickens to the east. This is probably the result of magnetic material in the till.

The seismic results shown in Figure 050.2B indicate the presence of a low velocity, Precambrian bedrock extending from the south to the north under a thin layer of till. The north seismic spread shows that the surface of the low velocity layer dips steeply. Just north of this seismic spread, the road begins to rise over an area of outcrop of mafic metavolcanics. It is evident that the fault between the low velocity Precambrian rock and the mafic metavolcanics must occur just north of the last seismic data point.

The magnetic survey along the Concession IV road extended beyond the north seismic spread to a distance of 400 m north of the 5-6 sideroad, with readings taken every 4 m. The line almost reached an exposure of mafic metavolcanics at the top of a hill. The magnetic profile in Figure 050.2B shows little or no variation over the southern part of the line, underlain by the low velocity Precambrian rock. Near the north seismic spread, the profile begins to increase, to form an anomaly of about 2000 gamma approaching the outcrop at the top of the hill. Such an anomaly is expected for a mafic volcanic rock containing magnetite. The magnetic profile is consistent with a fault contact with the mafic metavolcanics at about 400 m on the survey line.

CROOKSTON ROAD SITE RESULTS

The seismic and magnetic survey results for the Crookston Road site are shown in Figure 050.3. The figure shows results beginning 200 m along the survey line and extending 600 m to the east. At the western side, or the 200 m point of the survey line, the Upper Bobcaygeon Formation is identified by an outcrop with a velocity of 4570 m per second. Velocities of about the same value indicate that the bedrock surface of the Upper Bobcaygeon dips to the east, to about the 310 m mark. At this point, there is an abrupt rise in the bedrock surface, with a thinning of the overlying till. Also, the bedrock velocity increases significantly to 6360 m per second and higher. This high velocity bedrock continues to about the 600 m mark. In this high velocity section, the bedrock surface is irregular and forms a series of knolls. Farther to the east, the bedrock surface rises gently

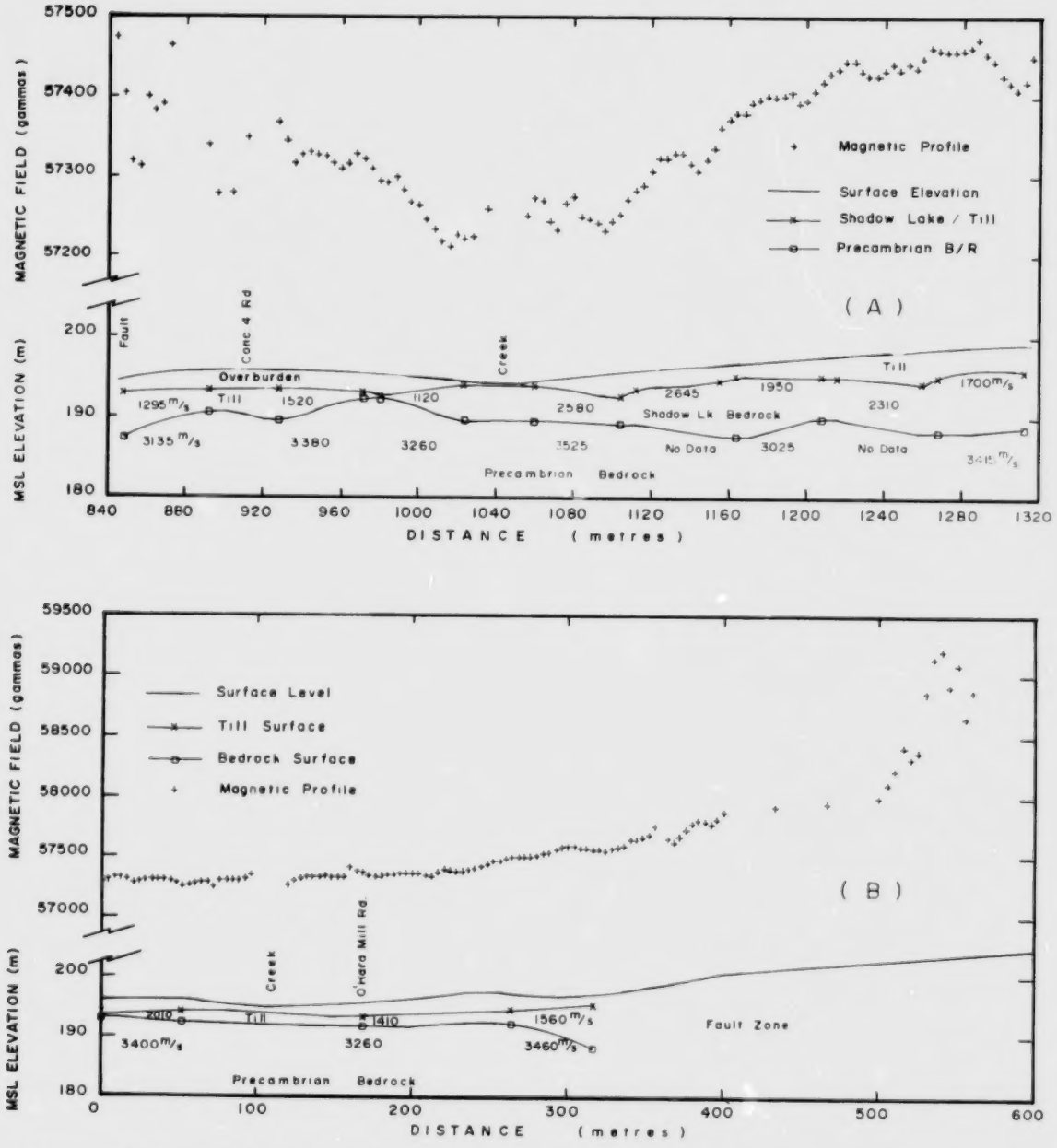


Figure 050.2. *Geophysical survey results for the O'Hara Mill site. (A) Along the 5-6 sideroad, from west to east. (B) Along the Concession IV road, from south to north.*

under a large hill of till. Here, the bedrock velocity decreases to 3990 m per second, indicative of a limestone. To the north, along the 18-19 sideroad, bedrock outcrop is Upper Bobcaygeon. At the Mean Sea Level (MSL) elevation of the bedrock surface in the magnetic profile, the bedrock would be Lower Bobcaygeon.

At about 270 m on the survey line, predominantly limestone boulders occur along the western fence of a field. At about 440 m on the survey line, predominantly large Precambrian boulders occur along the eastern fence of the field. These boulders have apparently been removed from the next lower field to the east. The high seismic velocity and undulating surface of the central bedrock section, compared to the smoother surface of the limestone sections to the west and east, suggest a possible band of Precambrian rock faulted on the west at about the 310 m mark, and on the east, at about the 600 m mark.

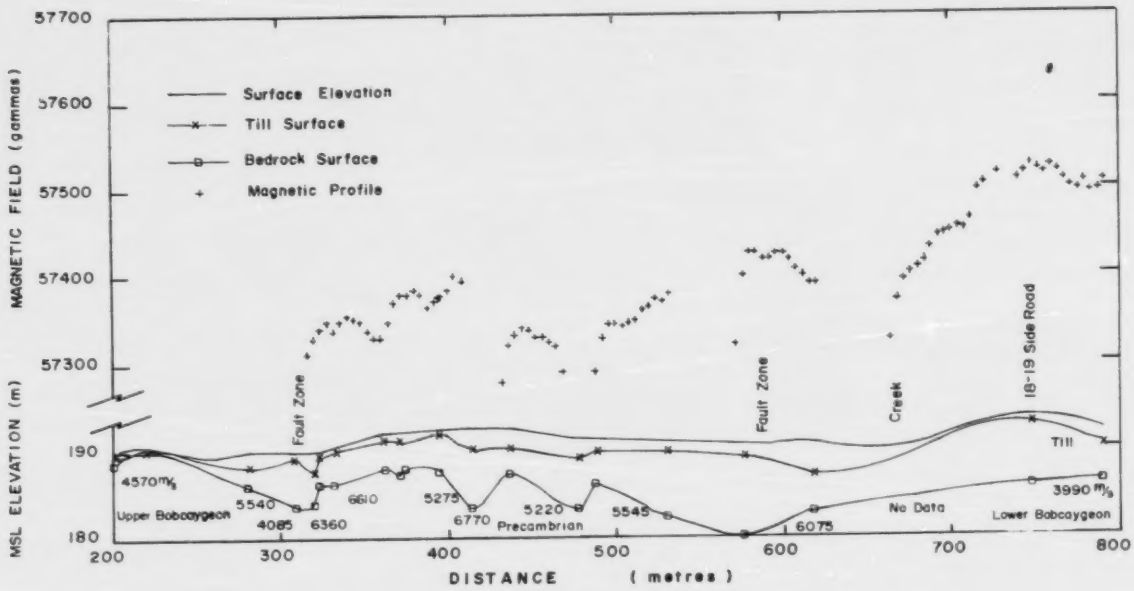


Figure 050.3. Geophysical survey results for the Crookston Road site.

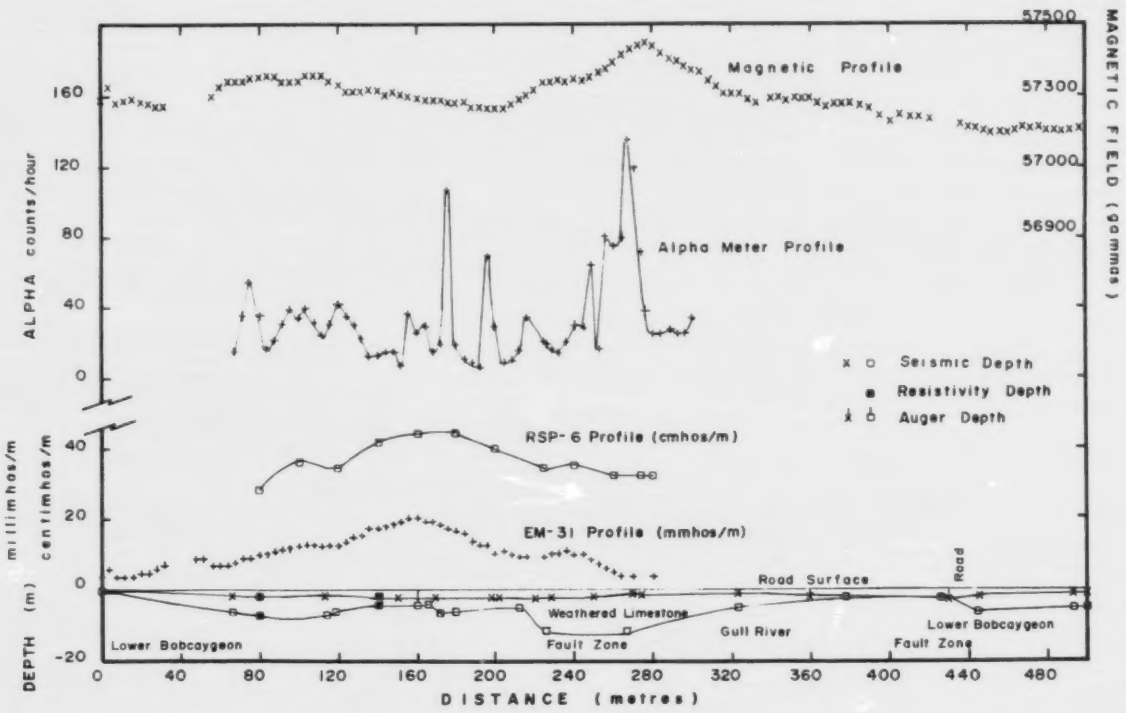


Figure 050.4. Geophysical survey results for the Buller Siding site.

The magnetic profile has small, irregular variations over the suspected band of Precambrian bedrock, but no significant anomaly. Over the hill of till at the eastern end of the survey line, the magnetic field increases over 100 gamma, indicating the presence of magnetic material in the till.

BULLER SIDING SITE RESULTS

The resistivity, alpha meter, and magnetic survey results from the 1987 work, together with the seismic and conductivity survey results from previous work (Thompson 1986), are shown in Figure 050.4.

The resistivity data have been converted to conductivity units to correlate with the previous EM-31 profile. The RSP-6 profile shows the same anomalous peak as the EM-31 profile. This confirms a subsurface conducting band in the bedrock at about 160 m on the survey line. Also, estimates of the depths to the weathered/broken limestone layer and to the deeper, more competent limestone layer, obtained from two resistivity measurements shown in Figure 050.4, are the same as depth estimates obtained from seismic studies.

The magnetic profile shows a small anomaly of about 60 gamma at about 100 m, and a larger anomaly of about 150 gamma at about 270 m on the survey line. This latter anomaly could be associated with the fault zone indicated by the bedrock depression.

The alpha meter profile shows twin anomalous peaks at about 170 m and 190 m, and a broader anomalous peak at about 260 m on the survey line. The latter anomaly is consistent with the larger magnetic anomaly. It is likely associated with radioactive minerals in the fault zone. The other two sharp peaks must result from thin veins in the bedrock carrying a small quantity of a radioactive mineral.

THOMASBURG SITE RESULTS

Five individual seismic spreads were shot in an attempt to locate an anticipated fault between the Lower Bobcaygeon Formation in the west and Precambrian granitic gneiss in the east. The three spreads on the old Thomasburg road just north of the Concession VI road (Figure 050.1) gave generally high velocities (5200 - 5800 m per second), but these values were not significantly high enough to conclude that the bedrock is Precambrian granitic gneiss. The bedrock in the western fault block was, therefore, assumed to be Lower Bobcaygeon. The two spreads on the Concession VIII road (Figure 050.1) gave velocities consistent with the Gull River Formation (about 5000 m per second), which crops out to the north along the old Thomasburg road. It was concluded that the fault against the Precambrian granitic gneiss must be farther to the east. A re-examination of the area led to a more precise location of the fault.

CONCLUSIONS

1. A better understanding of the stratigraphy and structural geology has led to a revision of the geological map of the Madoc fluorite area, in which the distribution of Precambrian and Paleozoic rock units, and the interpreted locations of normal faults are shown in considerable detail. This represents a significant improvement on previous mapping of the area, and should be of benefit to exploration companies.
2. Geological mapping and geophysical surveying results to date indicate general areas of high exploration potential for fluorite and other mineral deposits; for example, adjacent to fault zones and in the vicinity of fault junctions.
3. Conductivity/resistivity, magnetic, and radioactive anomalies are associated with the Buller Siding fault zone, where fluorite-bearing veins may be expected to occur.
4. Additional geological mapping and geophysical surveying are required to improve knowledge of the geology of the area, particularly with regard to the fault system. More evaluation of anomalous geophysical responses is necessary, especially for the direct exploration for fluorite-bearing veins.

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051. Pegmatites of the Bancroft Area, Southern Ontario

Bruce E. Goad

Project Geologist, Ontario Ministry of Northern Development and Mines, Bancroft.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Ontario and Canada.

INTRODUCTION

Granitic pegmatites are very common in the study area. In the past, these pegmatites were exploited, or at least explored, as a source of feldspar, quartz, mica, uranium, thorium, molybdenum, beryllium, and rare earth elements (REE). Past exploration for, and limited production from, the pegmatites peaked during the periods:

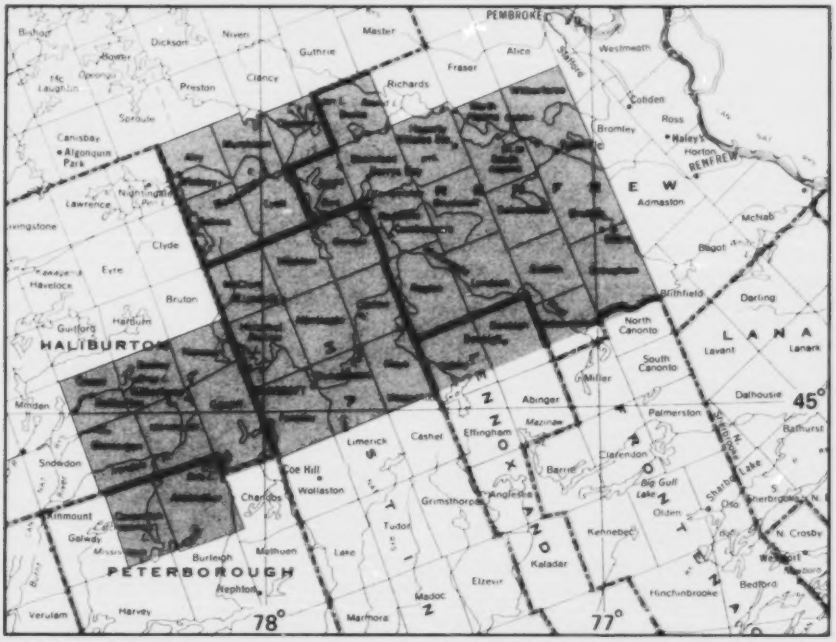
1. between 1917 and 1927, when many were explored for mica and/or feldspar deposits
2. between 1940 and 1947, when others were examined as sources of mica and/or beryllium
3. during the 1950s, when they were examined as a source of uranium

However, all of the pegmatite showings, including the larger dikes with some past development, are now poorly to very poorly exposed. Commonly, the internal structure of the pegmatite is no longer visible, and exposure is limited to the wall/border zone of the pegmatite on the walls of the old pits and trenches. Over the years, these pits and trenches have become overgrown, filled with debris, or have been flooded. The only active commercial pegmatite operations in the study area are the Rose Quartz pit and the Beryl pit pegmatites in Lyndoch Township, operated by Wal-Gem Lapidary for mineral specimens. Quartz was produced from the Comet Quartz pegmatite in Murchison Township in 1976 and 1977, but this quarry is currently inactive.

THE CURRENT PROGRAM

The current program was initiated in 1987, to examine the pegmatites occurring in the Grenville Province in the Bancroft area. During this program, all adequately exposed pegmatites will be mapped and sampled. Subsequently, an attempt to classify the larger pegmatite showings on the basis of their trace element content will be made. Previous studies by Storey and Vos (1981) and by Masson and Gordon (1981) mapped several of the larger showings, and classified the pegmatites on solely a descriptive basis.

Pegmatites are generally considered to have crystallized from melts somewhat enriched in incompatible elements (e.g. Rb, Cs, Li, Tl, Pb, B, and Fe^{3+}), which are not readily accepted into the crystal structure of most rock-forming minerals. These elements, therefore, tend to concentrate in the melt until the final stages of crystallization. The crystal structure of the feldspars (a mineral abundant in most peg-



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

matites) provides a suitable host for the incompatible elements. Accordingly, as their concentration increases in the late melts, it also increases in the feldspars that crystallized from these late melts.

Comparison of the level of fractionation attained by different pegmatites within each group or district can be made from comparison of their trace element content (Cerny 1982a). For this study of pegmatites in the Bancroft area, it was decided to study the blocky potassium feldspar in the pegmatites, because it is ubiquitous in these pegmatites, and can be readily sampled and cleaned for analysis. Ideally, the coarse, blocky K-feldspar in the intermediate (blocky K-feldspar + quartz) zone was sampled: this, where exposed, provided a relatively constant marker position in all of the sampled pegmatites for comparison of fractionation level.

PROGRESS

At the time of writing (September 1987), 76 of the known pegmatite occurrences in the Bancroft, Monteagle, and Nipissing areas had been examined and sampled. Most of these have also been mapped.

The pegmatites occur as both zoned and unzoned bodies; however, most of the zoned pegmatites are composed only of the following rudimentary zones:

Border Zone—plagioclase + K-feldspar + muscovite + biotite + quartz

Wall Zone—plagioclase + K-feldspar + quartz

Intermediate Zone(s)—K-feldspar + quartz

Core Zone—quartz (+K-feldspar)

Zoning in most of the pegmatites, where evident, is irregular and difficult to trace. Many of the unzoned pegmatites may in fact be zoned and the zonation, including the quartz core, may not be recognized because of poor surface exposure, or the pegmatite's position relative to the present erosional level.

Contacts of many of the pegmatites, where they are or can be exposed, are abrupt, but gradational (e.g. the Comet Quartz showing in Murchison Township). Some are distinctly gradational into the host rocks (e.g. the Dubblestein showing in Bangor Township). These observations, the simple mineralogy of the pegmatites (i.e. negligible to low, and then only local, REE, Be, and Nb mineralization) and the apparent lack of suitable adjacent "fertile" parent granitic intrusions, suggest that the pegmatites are "pegmatites of maximal depth formation" (Cerny 1982b).

No geochemical data had been received at the time of writing.

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052. Stratigraphy and Sedimentation of Carbonate and Associated Metasediments of the Grenville Supergroup in Southeastern Ontario

Hans D. Meyn

Regional Minerals Specialist, Ontario Ministry of Mines, Bancroft.

INTRODUCTION

The carbonate rocks of the Grenville Province in Ontario have a long history of contributing to the mineral production of Ontario. Iron was one of the earliest metals produced from Grenville marble-hosted deposits. In addition, graphite, zinc, and marble for building stone and for production of lime came from Grenville marble (Hewitt and Vos 1972; Storey and Vos 1981a, 1981b; Carter 1984; Malczak *et al.* 1985).

At present, the marbles yield: marble for filler, golf sand, chicken grit, mortar, and white bricks; marble chips for concrete facing and similar uses; talc; and dolomitic marble for the production of magnesium. In addition to the continuation of this production, potential is seen for future production of tremolite, wollastonite, graphite, and zinc.

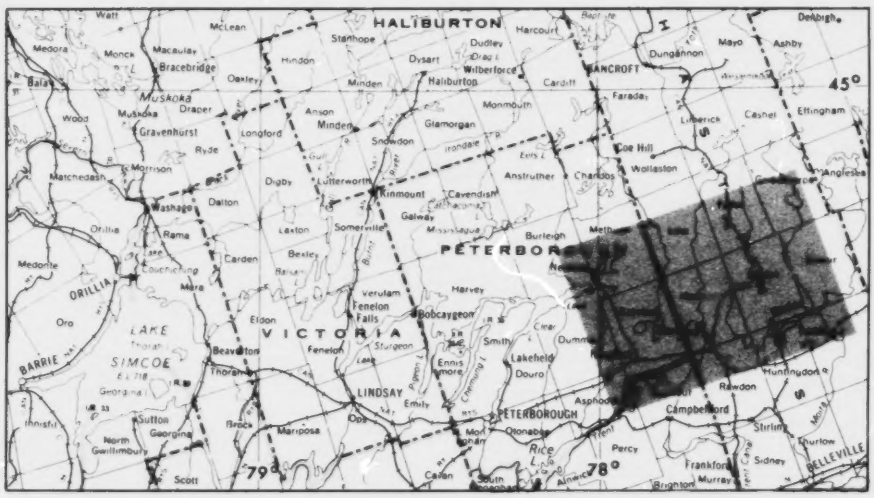
Although the carbonate rocks are widespread in the Grenville Province, economic extraction of the above commodities is possible only from those portions of sufficient purity (marbles) or impurity (graphite, zinc, tremolite, and wollastonite). Understanding the sedimentology and stratigraphy of the carbonates will assist in locating these economically important portions. This project was initiated to provide that understanding.

Field work was started, in 1987, in the least metamorphosed rocks in the Belmont-Madoc area. Initially, roadside and lakeshore exposures were visited to gain a preliminary insight into the local rocks. It is expected that, in future years, detailed mapping of selected areas will commence with concomitant establishment of at least local stratigraphic successions. Less accessible and more highly metamorphosed areas will be included in later phases of the study.

GENERAL GEOLOGY

There are large areas of sedimentary sequences dominated by carbonate (marble) in the Central Metasedimentary Belt of the Grenville Province. The general area of Belmont, Marmora, and Madoc Townships was selected for this study because fairly thick sequences of marble are present and, since they are near or in the "Madoc Metamorphic Low", they are most likely to retain primary sedimentary features. Although these rocks are in the metamorphic low, they are not structurally undisturbed; nevertheless, units can be traced for 3 to 4 km (Bourque 1981, p.78).

Little detailed work has been done on the sedimentary rocks in general, or on the marbles in particular. Among the earliest workers were Adams and Barlow (1910), who recognized amphibolite layers in marble as metasediments. More general overviews of the local and regional geology of the metasediments are given by Lumbers (1964) and Hewitt (1968). Recent detailed mapping by Bartlett and Moore (1985), and several theses associated with that project (Murray 1982; Bartlett 1983; Pilon 1981; deKemp 1984), have generated some detailed maps of Belmont and Marmora Townships, but geological interpretations have concentrated upon the volcanology of the area. An earlier study of the metasediments was initiated by Bourque (1981, 1982); some results from that study are contained in Bartlett and deKemp



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

(1987). An investigation of the chemistry of the marbles is reported in Grant and Kingston (1984).

In the field area, most of the carbonate metasediments consist of weakly foliated, light to dark grey, fine- to medium-grained marble, with mineral impurities such as diopside, tremolite, phlogopite, cummingtonite, quartz, pyrite, magnetite, hematite, and graphite.

It was found that the Grenville marbles show environments of deposition from shallow water, probably intertidal stromatolitic phases, to deep water turbiditic phases.

BIOSEDIMENTARY STRUCTURES

The recognition of possible fossilized life forms in the carbonate rocks of the Grenville Province dates back to Dawson (1865) who proclaimed an organic origin for the *"Eozoon canadense"* forms found by Sir William Logan in 1858 (Wilson 1957). *"Eozoon canadense"* comprises several similar but distinct morphologies. A biogenic origin for one of these forms, the "huntingdon" type, has recently gained general acceptance largely due to the contributions of M.S. Bourque (Bourque 1981, 1982; Bourque *et al.* 1982; deKemp 1984). This should not be interpreted as implying an organic origin for the other *"Eozoon canadense"* forms, as there may not be any genetic relationship between them and the "huntingdon" type (Hofmann 1971).

These Biosedimentary structures are stromatolites, which are among the most common and long ranging fossils in the geological record. They are preserved in other parts of the Central Metasedimentary Belt, as well as in the map area. Their widespread occurrence in the Precambrian, their extensive geographic distribution, and the existence of living modern analogues, make them valuable indicators of paleogeography and paleoenvironment, and thus important to stratigraphic analysis and mineral exploration.

FUTURE WORK

This report of activities is of necessity brief, given the preliminary stage of the project. Planned studies in 1988 include detailed mapping of Big Island in Belmont Lake, and in an area of more extensive outcrop, east of the Cordova gabbro pluton in Belmont and Marmora Townships. Such areas of better exposure are essential to establishing even local stratigraphy in the carbonates.

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053. Industrial Minerals, Rare Earth Elements and Building Stone in the Muskoka–Parry Sound–Nipissing Area

Christopher Marmont and Marcus Johnston

Geologists, Ontario Ministry of Northern Development and Mines, Dorset

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

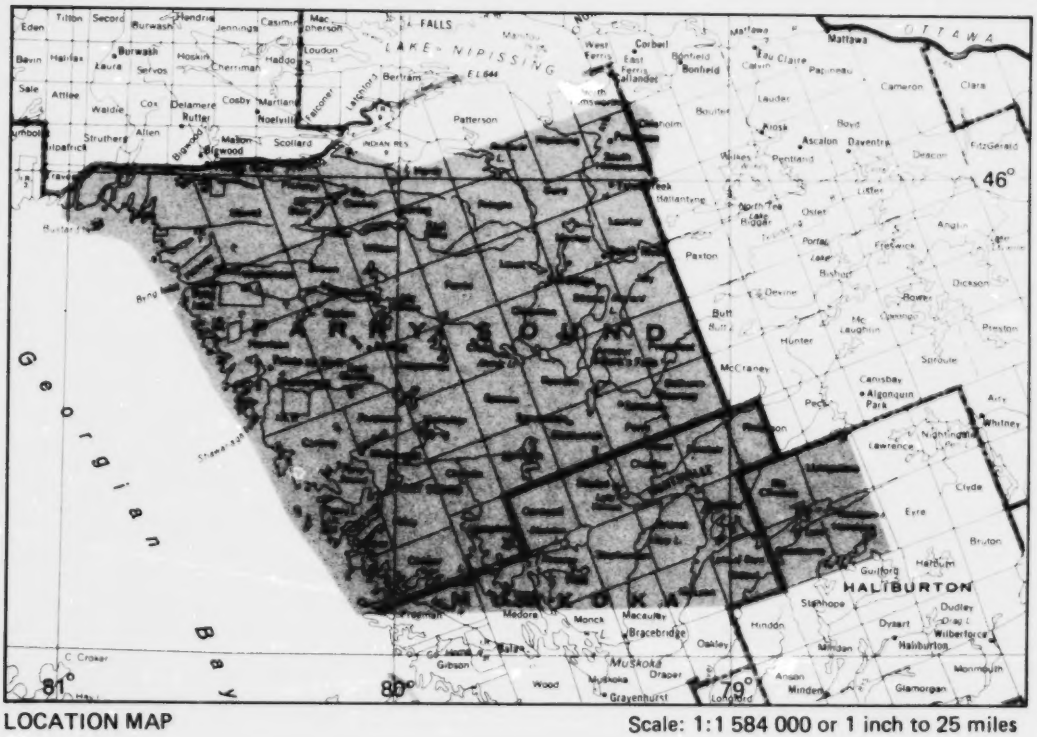
This report summarizes field work undertaken during the second year of a three-year project to evaluate the industrial mineral potential of the Muskoka-Parry Sound-Nipissing area (Location Map). The results of the first year's work are reported by Marmont (1986) and Marmont and Johnston (1987). Work performed during the 1987 field season concentrated on anorthosite, which has potential applications in the fabrication of glass, ceramics and insulation materials (mineral wool), and upon "limestone" (crystalline marble), which has applications as an acid neutralizer in industry and agriculture, as a flux, as a mineral filler, and many other uses. The building stone component of the project has concentrated on the evaluation of gneisses suitable for tile production. Some pegmatites have been investigated as possible sources of quartz, feldspar and rare earth elements. The results of this year's work will be reported more fully in an open file report in the spring of 1988.

MINERAL EXPLORATION

The history of mining and mineral exploration in the area has been described by Marmont (1986) and Marmont and Johnston (1987). Local activity in the industrial minerals field is largely focused on graphite (Garland 1987, and article 054, this volume), and some interest has been expressed in using local marble as agricultural limestone. Several mafic to ultramafic bodies are being explored for platinum group elements (Garland, article 046, this volume). Test pits have been opened on a flagstone occurrence near Magnetawan (Meadows and Fouts, article 070, this volume).

GENERAL GEOLOGY

The study area is located in the Central Gneiss Belt of the Grenville Province (Moore *et al.* 1986). It is a structurally complex area of ortho- and paragneisses, metamorphosed to upper amphibolite and granulite facies. An overview of the geology of the area is presented in Marmont and Johnston (1987). During 1987, geological mapping programs were conducted by A. Davidson of the Geological Survey of Canada



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

along the northern part of Georgian Bay, and by G.D. McRoberts and M.L. Tremblay (article 036, this volume) of the Ontario Geological Survey in the Arnstein-Dunchurch area, immediately north of the area mapped by Bright (1987) during 1986. J. Meadows and C. Fouts (article 070, this volume) of the Ontario Geological Survey conducted a study of flagstone deposits in the Parry Sound, Magnetawan-Burk's Falls and Dorset areas.

CURRENT PROGRAM

ANORTHOSITES

Work on anorthosite during the current field season consisted of a detailed mapping survey over part of the Whitestone Anorthosite in Hagerman Township, and reconnaissance of the bodies at Twelve Mile Bay in Freeman Township, and at Percy Lake-Haliburton Lake in Burton and Harburn Townships. No work was conducted in the Arnstein Anorthosite, which is generally more mafic than the other three bodies. Part of the latter body falls within the Ferrie River area mapped by McRoberts and Tremblay, and described elsewhere in this volume.

Detailed mapping in the Whitestone Anorthosite was aimed at delineating areas containing less than two percent iron, expressed as Fe_2O_3. Two percent iron approximates the upper limit which can be tolerated by the mineral wool industry, which uses a 2 to 3 inch lump rock feed. Naturally, anorthosites with low iron contents (small amounts of waste mafic minerals) will also be the best candidates for beneficiation for ceramic and glass applications. Estimation of iron content in the field was accomplished by first correlating the iron content of pyroxene, hornblende, magnetite and almandine garnet with their modal volumes, and performing point counts over clean outcrop areas where the mafic minerals contrast with the pale grey to white plagioclase. Representative samples were collected and analyzed in order to quantify the field estimates. It appears that the most anorthositic, iron-poor part of the Whitestone Anorthosite occurs within the oikocrystic facies immediately east of the orthopyroxene-bearing unit. The interpretation of results is continuing.

Reconnaissance of the Twelve Mile Bay and Percy Lake anorthosites indicates that parts of these bodies also contain low amounts of iron. Unlike the coarse-grained, predominantly oikocrystic Whitestone Anorthosite, they are fine grained (approximately 0.2 to 0.3 mm), and finely banded on a scale of 1 to 5 cm. Pale grey to white bands of anorthosite with a colour index of 1 to 3 alternate with bands of a darker anorthosite containing a medium grey-coloured plagioclase and as much as 10 to 12 percent mafic minerals. Analytical results show iron contents ranging from 1 to 3 percent Fe_2O_3. Field investigations are continuing at the time of writing.

MARBLES

Field investigations of marble occurrences are still underway at the time of writing. Work completed to date includes detailed mapping of the Gene Pawlech marble occurrence in lot 33, concession V, Spence Township (Marmont and Johnston 1987, p.77), and visits to the John McVittie property in lot 7, concession IX, McKellar Township (Marmont and Johnston 1987, p.71). In response to a request from a local farmer, a visit was made to marble occurrences in the Arnstein area in order to assess their suitability for use as agricultural limestone. A summary report on this question, accompanied by a map showing the known distribution of marbles in the Parry Sound area, was released on October 8, 1987. It is available for viewing at the Mines Library, Ontario Geological Survey, Toronto; at the Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Dorset; at the Ontario Ministry of Northern Development and Mines office in Parry Sound; and in offices of the Ontario Ministry of Agriculture and Food in Huntsville and North Bay. The summary report concludes that local marble is suitable for use as agricultural limestone, but that such use will depend on economic factors: largely the ease, and hence the cost, with which the marble can be quarried, and the degree to which silicate minerals and lithic inclusions can be separated from the carbonate. Naturally, transportation costs will be significantly reduced below those of current suppliers in southern Ontario. All the marbles are tectonic breccias, and most are calcitic. Dolomitic varieties are known in Christie and McDougall Townships. Ongoing field work is directed towards the chemical and geological characterization of all of the marbles in the area.

PEGMATITES

Evaluation of pegmatites as a source of silica, feldspar and rare earth elements is continuing. The Ambeau Mine in Henvey Township, a former feldspar producer, was mapped at a scale of 1:200, and the "Richore" feldspar pegmatite in Conger Township was sampled. It is planned to evaluate two or three more bodies before the end of the year, and results will be reported in the spring of 1988.

BUILDING STONE

The building stone component of the project has focused on gneisses. At the time of writing, most work has been performed in the Britt Domain. The objective of the programme is to determine whether gneisses comparable to those currently marketed by Brazil as 12 and 18 inch tiles exist in the Muskoka-Parry Sound-Nipissing area. Most attention has been directed to orthogneiss units delineated by Davidson *et al.* (1982). Large samples have been collected and sawn. Some of the more attractive varieties occur along the power line east of Ardbeg in Burton Township, where pink to mauve, medium-grained, quartzofeldspathic gneiss is well exposed (Unit 9 of Davidson *et al.* 1982); in the marginal, foliated, garnetiferous facies of the Whitestone Anorthosite, which is a light to medium grey colour, highlighted by streaks of garnet and hornblende; and in grey, partly migmatitic granodioritic gneiss (Unit 3 of Davidson *et al.* 1982) near Grundy Lake Provincial Park. Many banded pink and grey gneisses which appear attractive in outcrop become jaded and dark when sawn, owing to the loss of reflective mineral cleavages. The reconnaissance is continuing, with the object of determining which geological units appear to be the most pro-

spective, so that more detailed evaluation can follow next year on a small number of targets. This work would include assessment of joint patterns and competence of the gneisses and, possibly, the extraction of small blocks for the sawing of tiles at various orientations to the foliation and mineral lineation, and assessing different types of finishing.

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054. A Detailed Petrological Study of the Cal Graphite Limited Graphite Deposit in Butt Township, Central Ontario

M.I. Garland

Geologist, Ontario Ministry of Northern Development and Mines, Dorset.

INTRODUCTION

The study area was previously mapped on a scale of 1:2500 as part of a program to investigate graphite resources in central Ontario (Garland 1987). Since then, an area of several acres has been stripped by Cal Graphite Limited offering 100 percent exposure over their main graphite showing. A very detailed outcrop map of this exposure was produced by mapping it at a scale of 1 cm to 2 m. A topographical survey was completed at the same scale to allow compensation on the detailed map for the irregular relief of the exposure. Channel samples, at least 1 m in length, were taken across specific rock units in the outcrop. The map and samples were then used in the project reported herein - a detailed petrological study of the Cal Graphite Limited showing.

The goals of this study are to gain an understanding of the complex geology of the graphite-bearing rock units, to acquire more information about the distribution of graphite in the showing and the controls of that distribution, and to construct, with the aid of diamond-drill sections, a comprehensive, three-dimensional picture of the deposit.

GEOLOGY

LITHOLOGIES

Five map units have been defined for the detailed outcrop map. Two of these are graphite bearing.

Unit 1a is a quartz-biotite-graphite rock, usually very finely banded and tending to be schistose. This unit comprises the majority of the graphite-bearing rocks, but tends to contain less graphite than Unit 1b. Biotite is common, usually associated with and interlayered with the graphite.

Unit 1b is a massive quartz-graphite rock. Grain size in this unit varies from 0.5 to 5 mm, with graphite flakes being up to 5 mm in size. Unit 1b forms traceable bands within Unit 1a, is often tightly folded, and can be extremely contorted.

Unit 2a is a homogeneous, plagioclase-quartz-biotite-garnet rock. It is fine grained and very finely banded. Unit 2a contains inclusions of a fine-grained mafic rock, which appears to have originally been a dike, now boudinaged and rotated. Lenses of graphitic material also appear to be inclusions, now stretched into narrow bands. This unit occurs as blocks in Unit 1; the largest block occurs in the northern part of the outcrop, and smaller blocks occur at both the eastern and western ends of the outcrop.

LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

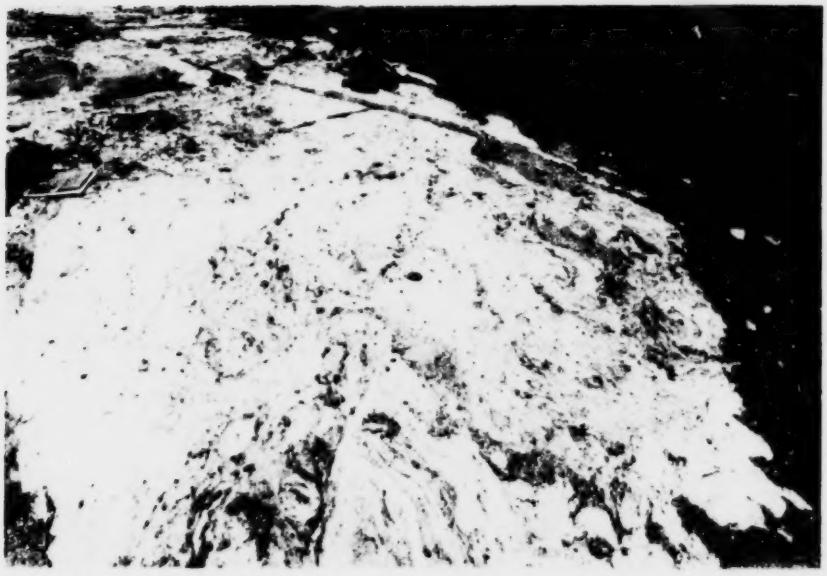

Photo 054.1. *Photograph of the eastern end of the outcrop area, showing the highly contorted foliation in the graphitic unit.*

Unit 2b is similar in composition to Unit 2a, but differs in structure; it has been termed "net-textured". The rock comprises a leucosome, consisting of quartz, plagioclase, garnet and some biotite, which surrounds areas up to 1.5 m in dimension of a plagioclase-hornblende melanosome. The melanosome is massive to weakly foliated, with the foliation being more pronounced near the edges of the unit. In more massive areas, a coronitic texture is apparent, in which garnet and hornblende surround plagioclase. The leucosome occurs as small veins within the melanosome, and also forms progressively larger areas which surround the massive-textured melanosome. This unit forms large blocks, several metres in size, which appear to "float" in Unit 1a. The blocks show rotation with respect to one another.

Unit 2c appears to be a derivative of Unit 2b. It consists of the leucosome of Unit 2b, and occurs as injections into fractures, or as large, pegmatitic patches. It is usually composed of quartz, plagioclase and garnet, with occasional large books of biotite.

STRUCTURAL GEOLOGY

The general tenure of the exposure is one of 10 to 20 m wide bands that trend northeast. In the northern part of the area mapped, the foliation also follows this trend. Scarp edges likewise trend northeast. In the southern and eastern parts of the exposure, the foliation direction is variable, reflecting a complex fold pattern. In some instances, the banding and foliation are extremely contorted, resembling the pattern in a marble cake, as seen in Photo 054.1. Dips are predominantly to the south, usually at 30° to 50°, and lineations always plunge to the south, at 30° to 40°.

Tight, isoclinal folds, with axes parallel to the overall northeast trend, characterize the eastern end of the outcrop. Folding is most predominant in the graphitic units, and bands of Unit 1b can be followed through three repetitions due to this tight folding. Photo 054.2 illustrates some of this folding. Both grain size and amount of graphite increase in fold noses. Unit 2b appears to have reacted in a brittle manner, forming boudins and large, rotated blocks. The more plastic graphitic units wrap around the blocks of Unit 2b, as shown in Photo 054.3, and, in extreme cases, the block of Unit 2b is left in the fold noses.

The fine bands of Unit 2a are crenulated, giving the rock a wavy appearance. Inclusions appear to be the result of disruption of a more competent unit, with ensuing boudins and rotated blocks. In some places, this more competent unit has been folded, resulting in sheath and rootless folds. Small, anastomosing shear zones occur in the graphitic units. Pegmatites fill some of these shears, and grade into veins of disaggregated feldspars.

CONTINUING WORK

Channel samples, 1 m in length, were taken every 5 m along the map grid in the western end of the outcrop, where the graphitic units are thicker and less contorted. Thin sections will be made from these samples. The graphite in selected samples will be examined in detail, after removal by flotation from crushed rock samples. The results of this work will be published in an Open File Report, to be released in the spring of 1988.

ACKNOWLEDGMENTS

The author would like to acknowledge Cal Graphite Limited for their continued support, and for permission to work on their property.

Photo 054.2. *Photograph to illustrate intense folding in Unit 1b. This fold can be followed through four noses.*

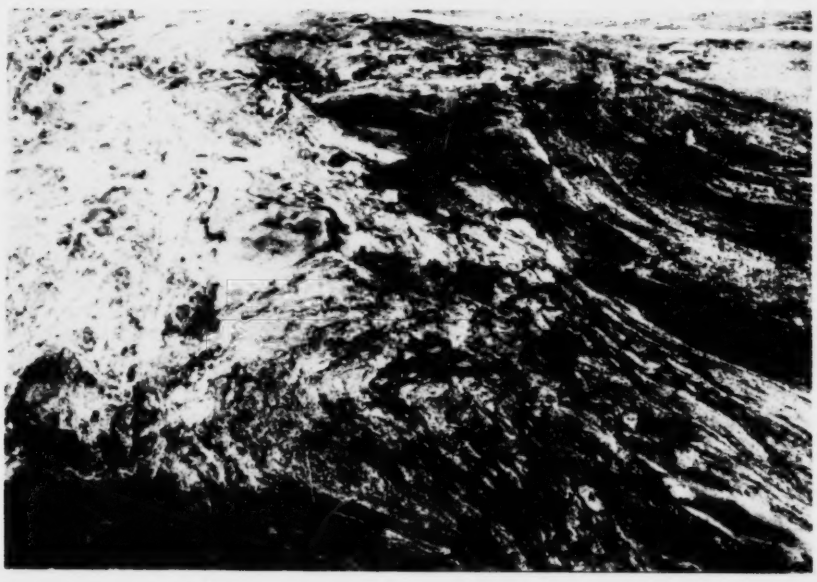

Photo 054.3. *"Net-textured" rock of Unit 2b, at the left of the photograph, grades into more foliated rock near the edge of the included block. The graphitic unit (Unit 1) wraps around the block of Unit 2b.*

REFERENCE

Garland, M.I.
1987: Graphite in the Central Gneiss Belt of the Grenville Province of Ontario; Ontario Geological Survey, Open File Report 5649, 222p., 33 figures, 5 tables, 13 photographs, and 6 maps in back pocket.

Special Studies

055. Geochemical Classification of Archean Volcanic Rocks

E.C. Grunsky[1], R.M. Easton[1], P.C. Thurston[1], L.S. Jensen[1], and J.M. Howe[2]

[1]Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Geological Assistant, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Investigation of methods of geochemical classification of volcanic rocks has continued since the establishment of a committee in 1985, composed of R.M. Easton (chair), E.C. Grunsky, L.S. Jensen, and P.C. Thurston (*see* Grunsky *et al.* 1986) to study various means of classifying Archean volcanic rocks. J.M. Howe has assisted the committee with, in particular, data processing, and the preparation of the komatiite database.

The establishment of the committee was based on the need to classify Archean volcanic rocks adequately, as well as to distinguish the extent of chemical alteration of Archean volcanic rocks. The ability to properly classify volcanic rocks as well as to determine the nature of any associated alteration has significant implications for mineral exploration strategies. Grunsky *et al.* (1986) discuss the usefulness of an adequate Archean volcanic rock classification scheme and provide a short review of commonly used geochemical classification schemes.

Grunsky *et al.*'s technique involves the assembly of a database of major and trace element chemical data from Ontario Archean volcanic rocks. The database includes analytical data from Archean volcanic suites from elsewhere and modern volcanic suites for comparative and testing purposes. By using a variety of statistical methods, the authors hope to determine the essential chemical components that characterize the chemical variation within and between a variety of volcanic suites. Currently recognized volcanic suites within the Archean are:

1. ultramafic-komatiitic
2. tholeiitic
3. calc-alkalic
4. alkalic

The data sets in each major magmatic association are to be tested by a variety of statistical methods to: a) develop a viable classification scheme for Archean volcanic rocks; and b) test for the presence and characterize the type(s) of alteration.

Tests of classification schemes and diagrams are made by comparison of data for specific groups or samples against data sets for relatively unaltered rocks representing each volcanic suite.

Compilation and classification of the komatiite suite of rocks was begun in 1986 (Grunsky *et al.* 1986) and has continued to the present. In addition, compilation and classification procedures for other Archean volcanic rocks from the tholeiitic and calc-alkalic suites were carried out in the past year, and some preliminary results are described below.

KOMATIITE DATADASE

Howe *et al.* (in preparation) have prepared a database, of komatiitic volcanic rocks from Ontario and around the world, which will soon be available in the form of a diskette containing the database in ASCII format, and a report explaining data compilation and storage procedures. The database includes 1293 major oxide and trace element whole-rock chemical analyses of komatiitic, ultramafic, and related rocks from Archean greenstone belts collected from the world literature. The database consists of two subgroups; an extrusive group of 1121 samples, and an intrusive group of 172 samples. Although the latter group is not strictly komatiitic using the definition of Arndt and Nisbet (1982), it is ultramafic, and provides a useful data set for comparing to extrusive komatiites. The separation into intrusive versus extrusive has been made on the basis of field observations, and it may be that some of these rocks were originally misclassified. At this time, no clear chemical distinctions between intrusive and extrusive rocks in the database have been found, although previous work has suggested that such a distinction can be made (Muir 1979). Additional work will be done on this problem.

The database consists of two parts. Part I is a report describing construction of the database and provides printouts to assist in day-to-day use of the database. Part II is the database itself, recorded on diskettes as an ASCII fixed format sequential file, usable on MS DOS/PC DOS microcomputers. Each part can be used independently.

The database is presented with a minimum of interpretation. Rock names are those given by the original author, in most cases on the basis of field work only, no matter how inappropriate they might seem. The chemical criteria for selecting komatiites and related ultramafic rocks was as broad as possible. This reflected the mandate of the committee to develop a classification scheme. During compilation, an attempt was made to ensure an even distribution of data from the various greenstone belts. Nevertheless, there is a bias toward data from the Abitibi and Barberton Mountain greenstone belts due to the profusion of komatiites and geological studies in these two regions.

The data was obtained from three main sources: a) the Ontario Geological Survey PETROCH database; b) PETROS (Mutschler *et al.* 1976); and c) literature searches.

The chemical criteria for the komatiites to be included in the database were defined by us as follows (by weight percent):

$$20.0 \leq SiO_2 \leq 60.0$$

$$0.0 < Al_2O_3 \leq 10.0$$

$$MgO \geq 10.0$$

From the PETROCH database, an initial selection of 1736 samples of komatiites including bona-fide komatiites, misnamed tholeiites, and some carbonate rocks, was drawn. A second selection was then made using the following criteria, for samples recalculated to 100 weight percent:

$20.0 \leq SiO_2 \leq 60.0$

$0.0 < Al_2O_3 \leq 10.0$

$MgO \geq 10.0$

$0.0 < TiO_2 \leq 0.2$

$0.0 < L.O.I. \leq 10.0$

These selection criteria reduced the database to 1293 samples. Komatiites were then separated into a file of 172 intrusive samples and 1121 samples of flows and pyroclastic rocks. If the field description described the sample as volcanic, then it was included in the extrusive data file.

CLASSIFICATION OF VOLCANIC ROCKS: DATA ANALYSIS TECHNIQUES

INTRODUCTION

Multivariate analysis is able to specify the principal chemical components involved in variation within an igneous suite or between igneous suites that are chemically distinct. Using this approach, systematic chemical variablility, based on various igneous or alteration/metamorphic processes, can be readily distinguished. This approach has been used by LeMaitre (1976) to classify a broad range of both volcanic and plutonic rocks.

Two statistical methods of determining distinct chemical trends within a sample population of geochemical data obtained from igneous rocks are correspondence analysis and dynamic cluster analysis. A discussion of correspondence analysis is given by Davis (1986) and dynamic cluster analysis is described and discussed by Diday (1973) and Lefebvre and David (1977).

Comparison between a number of samples with analytical data for 15 elements (i.e. 15 dimensions) is a difficult task. If the number of distinguishing criteria can be reduced from 15 to 5, then comparison between the samples will be much easier. The principle behind factor analysis is to represent the data in terms of a number of axes (factors) that describe the distribution of the data in fewer dimensions than the original data. Each factor can be thought of as describing a geological process. These geological processes include primary processes such as differentiation (partial melting, crystal fractionation, etc.) as well as secondary processes that include alteration (carbonatization, silicification, alkali depletion, etc.). In a suite of unaltered volcanic rocks, there is generally an inverse relationship between (Na, K) and (Ca, Mg, Fe^{+2}). If the data distribution were governed only by these components, then a plot of the compositional variation would be dominantly along one axis, illustrating a differentiation trend (i.e. Harker diagrams). If the rocks within a given suite, however, have been altered by some process such as carbonatization, then not only are the data distributed along a direction defined by its petrogenesis, but also along an axis that describes the departure of the data from an igneous trend by one or more components associated with the alteration process (for example CO_2). In correspondence analysis, the factors are calculated from a matrix composed of columns of chemical components and rows of samples. The factors are determined by the computation of eigenvalues that represent systematic distribution of the data based on component abundances.

The authors favour correspondence analysis as a multivariate technique since it allows the simultaneous projection of both the sample and variable factor scores in the same factor space. Also, correspondence analysis allows for the computation of actual and relative contributions of variables to the factor space. The actual contribution that a variable makes is the amount of variation (expressed as a percent of the total variation) that a variable contributes to a given factor. The relative contribution indicates how the variable is distributed over the factors that define the factor space.

KOMATIITES

Multivariate data analysis was carried out previously by Grunsky *et al.* (1986) using the part of the komatiite database in which it was demonstrated that the primary geochemical variation of komatiites is controlled by Mg, Ca, and Al, the most significant chemical components. Correspondence analysis shows that 69.27% of the geochemical variation of the rocks of the komatiite database can be attributed to the first factor (Factor 1) of the analysis. Within this first factor, Mg, Ca, and Al vary most widely and are the elements that best distinguish variation within the suite. Also, Ti, Ni, Cr, and Si variation is primarily accounted for by this first factor, but does not contribute significantly to the primary variation of komatiites relative to Mg, Ca, and Al (*see* Grunsky *et al.* 1986, Table 031.3, p.156).

Less significant factors in the selected group of samples represent alteration. Factor 2, 9.52% of the total data variation, is due to hydration and/or carbonatization. Sodium and calcium alteration are accounted for in Factor 3, 6.64% of the total data variation. Factors 4 and 5, 4.81 and 4.0% of the total data variation respectively, are part of the misclassified samples that are probably tholeiitic in origin.

Dynamic cluster analysis (*see* Grunsky *et al.* 1986 for an explanation) also indicates that the primary compositional variation of komatiites is dominated by Mg, Al, and Ca.

Subsequent evaluation of the komatiite data has focused on determining the components which best reflect the primary compositional variation, and which reflect secondary processes. When rocks are classified using schemes that require only two or three components (i.e. SiO_2 versus Na_2O+K_2O, Zanettin 1984; Irvine and Baragar 1971; Jensen 1976) it is difficult to notice the effects of alteration or misclassification. An example of this is illustrated in Figures 055.1a and 055.1b and Tables 055.1a and 055.1b. These two tables show the results of correspondence analyses applied to major element analyses of 928 samples selected from the komatiite database.

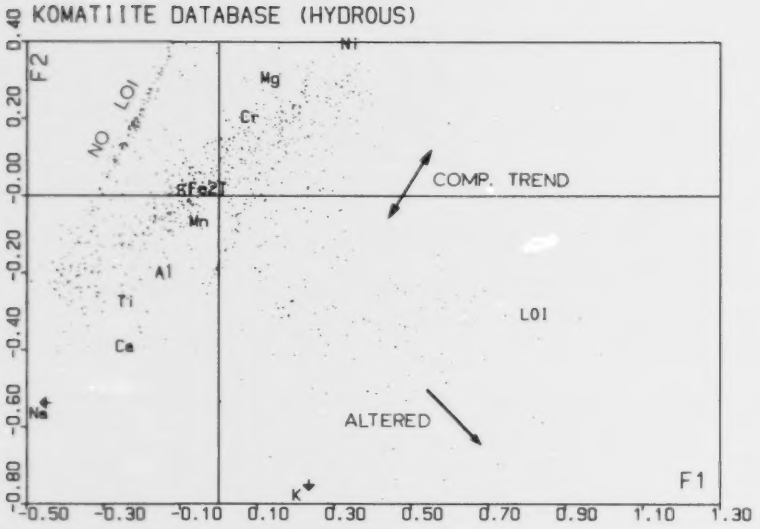

Figure 055.1a. *Projection of sample and variable factor scores on the F1-F2 plane from correspondence analysis. The bulk of the samples form a broad band that represents the compositional variation due to fractionation. Samples that plot toward the positive end of the F1 axis tend to be enriched in components represented by Loss on Ignition (L.O.I.). Samples that have little or no L.O.I. form a tight group of points defining a line in the upper left part of the diagram.*

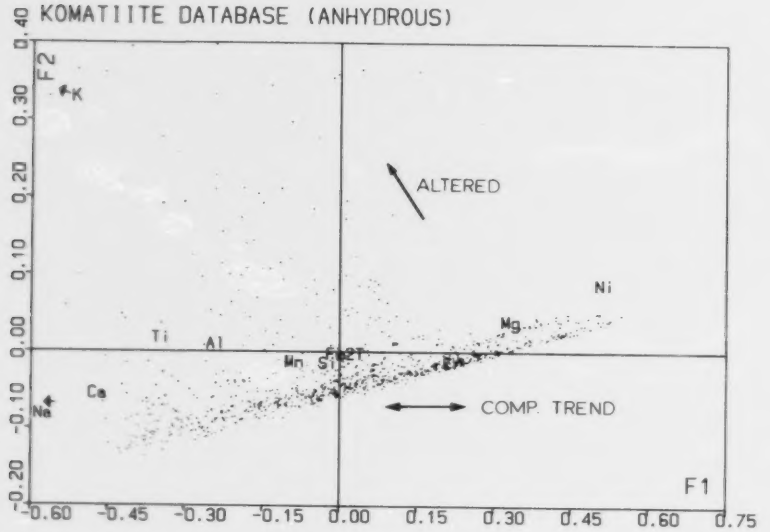

Figure 055.1b. *Projection of sample and variable factor scores on the F1-F2 plane from correspondence analysis for samples recalculated volatile free (no L.O.I.). Note how the bulk of the samples form a narrow band reflecting the compositional variation due to fractionation, in contrast to the broad band of samples in Figure 055.1a where volatiles have been included. Samples that plot toward the positive end of the F2 axis tend to K-enriched.*

Table 055.1a shows the results for the samples when L.O.I. (loss on ignition) was included in the data and Table 055.1b shows the results when L.O.I. was not used. Both analyses used samples in which the components were recalculated to 100 percent. Since komatiite rocks are subject to significant hydration and/or carbonatization, there is a decrease in the significance of the eigenvalue and corresponding eigenvectors which account for the compositional variation due to fractionation. This decrease is partly due to the closure effect common when using constant sum data (an increase in the number of significant variables), but is also due to the compositional variation due to fractionation. Thus, the second eigenvalue of Table 055.1a is less than the first eigenvalue of Table 055.1b although both eigenalues represent compositional variation due to fractionation. In fact, the effect of alteration is so significant that it accounts for the largest eigenvalue in Table 055.1a.

Both analyses indicate that the primary factor accounts for a substantial amount of the variation (42.6 and 53.6% respectively); however, examination of the contributions of the variables between the analyses (Tables 055.1a and 055.1b) indicate significant differences. The first factor of Table 055.1a shows that L.O.I. dominates the first factor, contributing 72% to the variation of the data within the first factor. This factor basically reflects those samples whose L.O.I variation exceeds the variation of the primary Mg, Ca, and Al compositional variation. The second factor of Table 055.1a represents 30.5% of the total data variation in which Mg, Cr, Ni, Ca, Al, Cr, and Ni dominate the factor. This factor represents compositional variation due to fractionation. The third factor of Table 055.1a indicates that rocks enriched in K are produced by K-metasomatism.

TABLE 055.1a. CORRESPONDENCE ANALYSIS OF EXTRUSIVE AND INTRUSIVE SAMPLES FROM THE KOMATIITE DATABASE.

	EIGENVALUES	% OF VARIATION
	0.06502091	42.59
	0.04655880	30.50
	0.01778353	11.65
	0.00837653	5.49
	0.00657145	4.30
	0.00388124	2.54
	0.00240930	1.58
	0.00083855	0.55
	0.00064082	0.42
	0.00044511	0.29
	0.00014414	0.09

Absolute and Relative Contributions of the Variables

	AC(1)	RC(1)	AC(2)	RC(2)	AC(3)	RC(3)	AC(4)	RC(4)	AC(5)	RC(5)
Si	7.64	97.44	0.00	0.00	0.09	0.30	1.36	2.23	0.02	0.03
Al	2.47	26.33	5.82	44.44	0.01	0.03	2.88	3.96	23.43	25.24
Fe_2T	0.93	25.11	0.01	0.17	0.02	0.16	0.88	3.07	26.15	71.49
Mg	4.53	12.12	43.94	84.27	1.12	0.82	1.98	0.68	7.79	2.11
Ca	7.57	23.74	24.29	54.53	4.10	3.51	33.59	13.57	14.65	4.64
Na	3.63	22.84	3.07	13.85	0.20	0.34	56.10	45.51	27.45	17.47
K	0.14	0.48	4.89	11.97	92.72	86.77	1.62	0.71	0.17	0.06
Ti	0.45	43.35	0.75	52.15	0.00	0.11	0.27	3.35	0.11	1.03
Mn	0.01	26.96	0.02	32.49	0.02	9.78	0.07	16.89	0.07	13.88
LOI	72.43	85.24	16.66	14.04	1.70	0.55	1.12	0.17	0.06	0.01
Cr	0.01	7.36	0.16	74.59	0.01	1.69	0.12	9.89	0.10	6.46
Ni	0.19	40.81	0.38	58.11	0.01	0.61	0.01	0.38	0.00	0.10

TABLE 055.1b. CORRESPONDENCE ANALYSIS OF INTRUSIVE AND EXTRUSIVE SAMPLES FROM THE KOMATIITE DATABASE, RECALCULATED TO 100% (WEIGHT), ANHYDROUS.

	EIGENVALUES	% OF VARIATION
	0.05482848	53.55
	0.02027683	19.81
	0.01035321	10.11
	0.00720694	7.04
	0.00443177	4.33
	0.00302544	2.96
	0.00093877	0.92
	0.00069064	0.67
	0.00045960	0.45
	0.00016829	0.16

Absolute and Relative Contributions of the Variables

	AC(1)	RC(1)	AC(2)	RC(2)	AC(3)	RC(3)	AC(4)	RC(4)	AC(5)	RC(5)
Si	1.32	47.59	1.06	14.15	3.47	23.61	0.02	0.10	4.99	14.56
Al	7.95	58.90	0.00	0.01	2.51	3.51	20.00	19.47	30.27	18.12
Fe_2T	0.11	1.38	0.05	0.20	3.86	8.78	20.39	32.30	58.84	57.33
Mg	47.08	95.34	1.39	1.04	3.75	1.43	8.12	2.16	0.16	0.03
Ca	32.76	76.56	1.39	1.20	42.43	18.73	9.99	3.07	2.34	0.44
Na	5.88	29.95	0.17	0.33	43.43	41.74	41.22	27.57	1.00	0.41
K	3.02	7.85	95.89	92.12	0.00	0.00	0.05	0.02	0.05	0.01
Ti	1.11	84.01	0.00	0.08	0.32	4.56	0.04	0.41	1.78	10.93
Mn	0.04	41.02	0.00	1.45	0.10	21.05	0.05	6.99	0.34	29.48
Cr	0.16	80.93	0.00	0.81	0.07	6.72	0.13	8.36	0.08	3.17
Ni	0.57	93.83	0.04	2.45	0.06	1.77	0.01	0.15	0.14	1.80

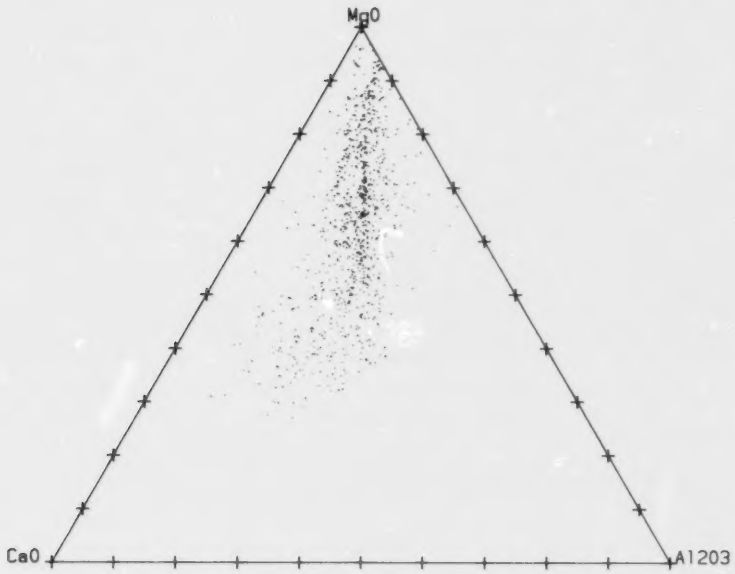

Figure 055.2a. *CaO-MgO-Al_2O_3 ternary plot of 928 samples from the komatiite database. This diagram shows maximum variation of the samples with respect to the chemical components used relative to the diagrams of Figures 055.2b and 055.2c.*

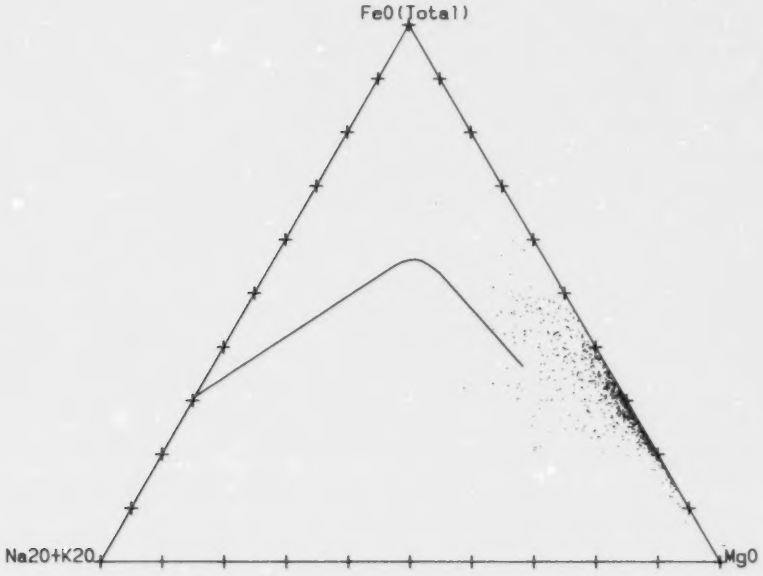

Figure 055.2b. *Na_2O+K_2O-$FeO(T)$-MgO (AFM) ternary plot of 928 samples from the komatiite database. This diagram does not show the range of komatiite composition as well as Figure 055.2a.*

Table 055.1b, on the other hand, shows that the first and most significant factor (53.5% of the total data variation) is produced by variation in Mg, Ca, Al, Ni, Cr, and Ti and the second factor of Table 055.1b is dominated by K-alteration. The differences between these processes is shown graphically in Figures 055.1a and 055.1b, where the sample factor scores are projected onto the F1-F2 plane. In Figure 055.1a, the variation of the data along the F1 axis reflects the amount of L.O.I. in the sample, and the F2 axis represents compositional variation due to fractionation. It is significant to note that most samples show some effect from L.O.I. but still plot within a broad band that represents primary compositional variation. A great number of samples, however, plot away from the main compositional trend line. These samples are L.O.I.-enriched and it is doubtful that the anhydrous compositions of these samples reflect the original component abundances since hydration/carbonatization results in the loss and/or addition of components such as K, Na, and Ca. Figure 055.1b shows the same samples that have been analyzed without L.O.I. Notice that the compositional trend line defined by Ni, Mg, Cr, Ca, and Si is well defined relative to Figure 055.1a. The most significant major oxides useful in displaying komatiite chemistry are Mg, Ca, and Al. Samples that plot away from this line are K-enriched (from the second factor). Although the samples plot along a well-defined line, the samples may be altered to the point that their position on the

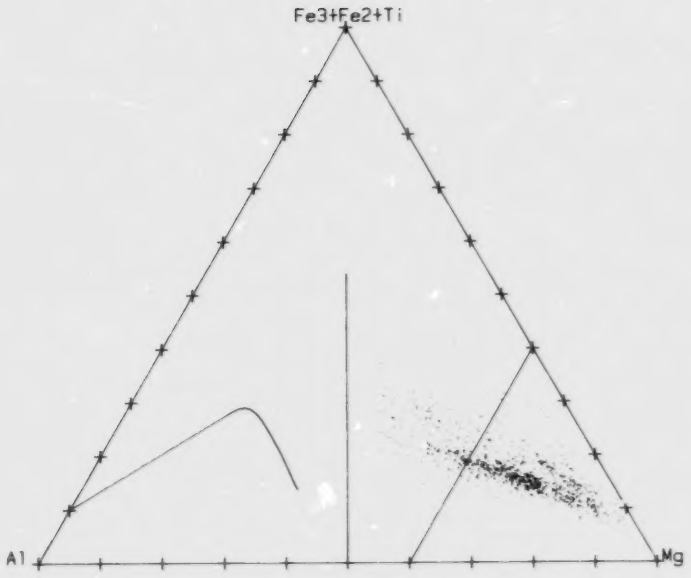

Figure 055.2c.
Al-Fe+Ti-Mg ternary plot of 928 samples from the komatiite database. This diagram shows compositional variation of komatiites with respect to Fe and Ti relative to Figure 055.2a.

TABLE 055.2. CORRESPONDENCE ANALYSIS OF 100 ABITIBI KOMATIITES, 100 ABITIBI THOLEIITES, AND 100 ABITIBI CALC-ALKALIC VOLCANIC ROCKS.

	EIGENVALUES	% DATA VARIATION
	0.12981205	63.95
	0.02825758	13.92
	0.02052628	10.11
	0.01023183	5.04
	0.00692362	3.41
	0.00431792	2.13
	0.00230555	1.14
	0.00057165	0.28
	0.00005673	0.03

Absolute and Relative Contributions of the Variables

	AC(1)	RC(1)	AC(2)	RC(2)	AC(3)	RC(3)	AC(4)	RC(4)	AC(5)	RC(5)
Si	8.33	75.05	2.10	4.12	13.75	19.58	0.12	0.08	2.43	1.17
Al	10.32	94.38	0.10	0.21	2.89	4.18	1.71	1.23	0.01	0.00
Fe_2T	1.05	9.93	23.78	49.13	11.71	17.58	22.51	16.84	12.87	6.52
Mg	54.58	93.10	6.43	2.39	16.26	4.39	0.77	0.10	0.23	0.02
Ca	0.23	2.43	4.47	10.41	33.31	56.43	32.26	27.24	6.12	3.49
Na	7.52	83.07	0.34	0.81	1.44	2.52	15.49	13.49	0.19	0.11
K	0.46	7.12	1.89	6.41	1.53	3.77	15.98	19.59	76.11	63.12
Ti	0.62	26.24	2.25	20.81	4.21	28.37	6.14	20.60	1.75	3.98
Mn	0.03	20.83	0.24	38.60	0.27	30.89	0.12	6.85	0.07	2.83
LOI	16.87	52.25	58.39	39.36	14.62	7.16	4.91	1.20	0.24	0.04

diagram does not represent an "original" sample composition relative to other samples.

Figures 055.2a, 055.2b, 055.2c show the same samples plotted on the CaO-MgO-Al_2O_3 (055.2a), AFM (055.2b) and Al-Fe + Ti-Mg (055.2c) diagrams. These diagrams display only a limited amount of variation relative to Figure 055.1b. Of the three diagrams, Figure 055.2a, in which CaO-MgO-Al_2O_3 are plotted, displays the maximum variation of data relative to other conventional petrologic diagrams, as in Figures 055.2b and 055.2c. It can be seen in Table 055.1b that Mg, Ca, and Al account for 87.79% of the variation of the first factor (absolute contribution) and indicates that these variables are the best choice for displaying primary compositional variation. Figure 055.2b is inadequate for properly displaying maximum variation of komatiite chemistry since Ca and Al are not used. Also, only 56.09% of the data variation

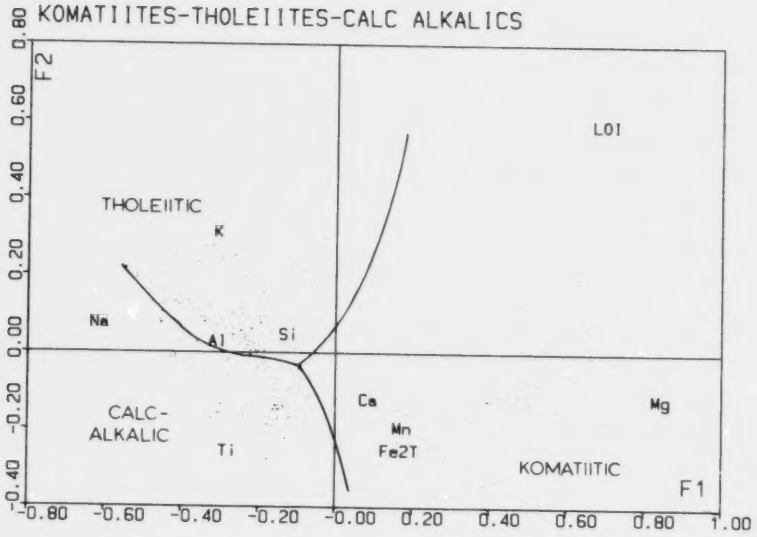

Figure 055.3. *Projection of sample and variable factor scores onto the F1-F2 plane from correspondence analysis applied to 100 Abitibi komatiites, 100 Abitibi tholeiites, and 100 Abitibi calc-alkalic volcanic rocks. The komatiitic and calc-alkalic–tholeiitic fields are distinct, based on the tendency of Mg enrichment of komatiites and their provenance to hydration/carbonatization. The tholeiites and calc-alkalic fields are also distinct but due to K-metasomatism of some of the tholeiites and the transitional nature of tholeiite–calc-alkalic fractionation the fields overlap.*

of the first factor (absolute contribution) of Table 055.1b is accounted for by the AFM variables. Figure 055.2c shows the komatiite compositional variation relative to Fe, Ti, Mg, and Al. Table 055.1b shows that 56.25% of the data variation of Factor 1 is accounted for by these variables. The compositional variation of the komatiite is also displayed on this diagram but not to the same degree as the Al_2O_3-MgO-CaO diagram of Figure 055.2

An important point must be emphasized—none of the diagrams in Figure 055.2 indicate that the rocks have been subjected to alteration in the form of hydration/carbonatization or K, Na-metasomatism. These samples may display an overall petrologic trend, but based on the diagrams of Figure 055.1 where there are obvious effects of alteration on many samples, it is impossible to tell if any alteration has occurred.

THOLEIITE AND CALC-ALKALIC ROCKS

Currently the committee is compiling data from the PETROCH database, PETROS (Mutschler *et al.* 1976), and IGBA (Li and Chayes 1983) to build a representative database of Archean tholeiites, and calc-alkalic and alkalic volcanic rocks. This work is still in progress; however, a preliminary examination of selected groups of data representing three volcanic suites, and the application of statistical procedures to distinguish these various suites, is presented here.

Table 055.2 shows the results of correspondence analysis applied to 300 samples consisting of 100 komatiites, 100 tholeiites, and 100 calc-alkalic volcanic rocks. The komatiites are Abitibi komatiites selected from the komatiite database, the calc-alkalic rocks are from the Blake River Group of the Abitibi greenstone belt, and the tholeiites were selected from the Kenojevis Group in the Abitibi greenstone belt. The tholeiite and calc-alkalic samples were selected for the Ontario Geological Survey PETROCH database. From correspondence analysis, the results indicate that the first factor accounts for 63.95% of the data variation. Within this factor Mg, Al, Si, and Na account for most of the variation. Within the second factor, FeO^* and L.O.I. contribute most significantly and the third factor is dominated by Ca, Ti, Mn, and Fe_2 (total). When the sample scores are projected into the F1-F2 plane (Figure 055.3), the three volcanic groups are clearly distinguished. Komatiitic rocks are associated with Mg, Ca, Mn, and Fe_2 (total) enrichment relative to the other suites. The komatiites also show consistently high L.O.I. values and a unique position on Figure 055.3 relative to the two other volcanic suites. This is largely due to the tendency of komatiitic rocks to undergo hydration/carbonatization. The tholeiitic suite tends to cluster around Ti, Fe, and Ca enrichment, while the calc-alkalic group is associated more closely with Na, Al, K, and Si enrichment. There is some overlap of the calc-alkalic–tholeiite fields on the F1-F2 projection. This overlap is due to alteration of some of the tholeiitic samples in the form of K-metasomatism. This test case involves a limited number of samples (300). As the sample size increases, there will most likely be a tendency for the fields of the various suites to merge when projected on a given factor plane. However, the suites may still be distinct in the factor space and it may be necessary to use two or more factor plane projections to distinguish the different suites.

Figures 055.4a, 055.4b, and 055.4c show samples from the three suites plotted on CaO-MgO-Al_2O_3,

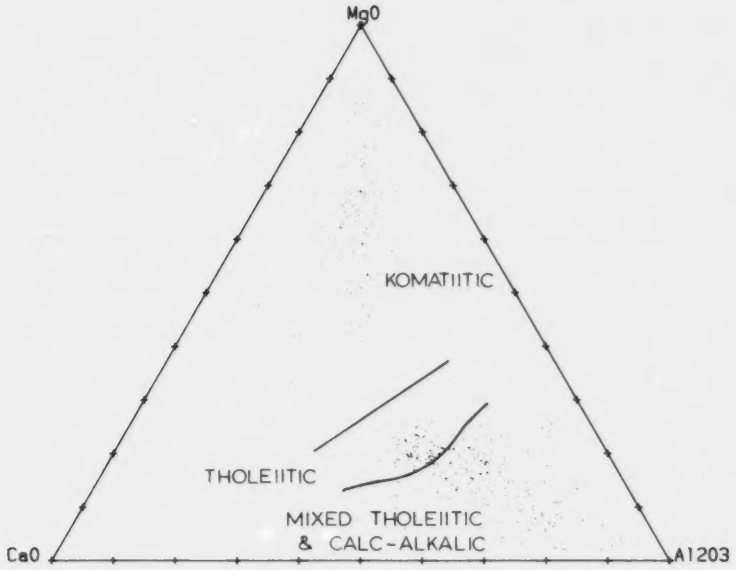

Figure 055.4a.
CaO-MgO-Al_2O_3 ternary plot of 100 Abitibi komatiites, 100 Abitibi tholeiites, and 100 Abitibi calc-alkalic volcanic rocks. The komatiitic rocks are quite distinct from the calc-alkalic and tholeiitic rocks. The diagram does not separate the calc-alkalic volcanics from the tholeiitic volcanics as well as Figures 055.4b and 055.4c.

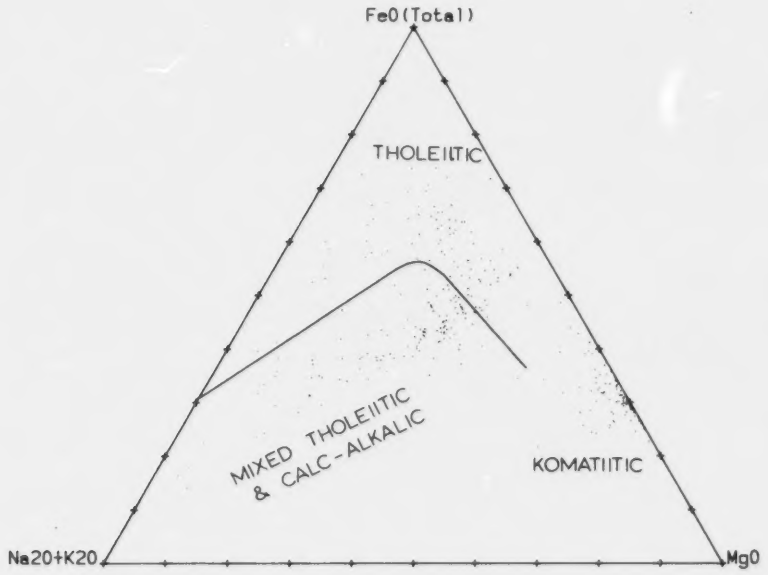

Figure 055.4b.
Na_2O+K_2O-$FeO(T)$-MgO (AFM) ternary diagram of 100 Abitibi komatiites, 100 Abitibi tholeiites, and 100 Abitibi calc-alkalic volcanic rocks. Note that the komatiites do not display the compositional variation very clearly while the calc-alkalic and tholeiitic rocks are clearly more distinct and display a wide range of compositional variation.

AFM, and Al-Fe+Ti-Mg ternary diagrams. In Figure 055.4a, the komatiites are clearly defined as a cloud of points near the Mg apex. The tholeiitic and calc-alkalic samples are clearly distinct from the komatiites as they tend toward the Al_2O_3 apex. The tholeiites and calc-alkalic rocks are mineralogically distinct from komatiites because there is a tendency toward plagioclase enrichment in the tholeiite to calc-alkalic trend. The tholeiites and the calc-alkalic rocks are more difficult to distinguish because they appear to merge with each other on both the factor score diagrams (F1-F2 planes) and on the three ternary diagrams. The overlap between the tholeiite and calc-alkalic fields is more pronounced in Figures 055.4a and 055.4b relative to minimal overlap in Figures 055.3 and 055.4c. Other factor score projections may show more clearly the distinctions between the tholeiitic and calc-alkalic suites. The AFM (Figure 055.4b) and the Al-Fe+Ti-Mg (Figure 055.4c) diagrams clearly distinguish between the tholeiite and calc-alkalic suites in contrast to Figure 055.4a. This distinction is brought about by the iron enrichment trend which is the most fundamental characteristic feature of the tholeiitic suite. It is worthwhile to note that in each of Figures 055.4a, 055.4b, and 055.4c, the tholeiitic rocks merge into the calc-alkalic field; however, the calc-alkalic rocks do not merge toward the tholeiite field. The reason that this occurs is due to the fact that tholeiitic rocks can undergo alteration in the form of K-metasomatism as well as at the

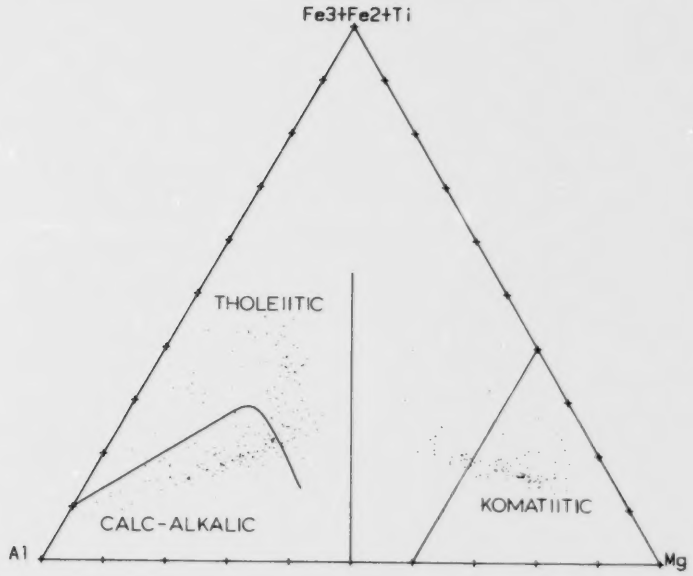

Figure 055.4c. *Al-Fe+Ti-Mg ternary diagram of 100 Abitibi komatiites, 100 Abitibi tholeiites, and 100 Abitibi calc-alkalic volcanic rocks. This diagram is a compromise between the compositional variation of Figures 055.4a and 055.4b. Compositional trends of all three suites are delineated but not as clearly as in the other two diagrams.*

expense of Fe depletion. Thus, the distinction between calc-alkalic rocks and tholeiites can be masked by this problem. This problem will also be addressed in the study.

Thus, if a ternary diagram is to be used to distinguish tholeiites and calc-alkalic rocks, then the Al-Fe+Ti-Mg and AFM diagrams (Figures 055.4c and 055.4b) are preferred in that order. To most effectively distinguish primary compositional variation (fractionation) within the komatiitic suite, the CaO-MgO-Al_2O_3diagram of (Figure 055.4b) is preferred.

FUTURE WORK

Future work involves the development of databases of tholeiitic, calc-alkalic, and alkalic volcanic rocks from Ontario. These databases will be constructed such that typical composites of suites will be presented by areas (greenstone belts) within Ontario. These databases will provide typical suites against which other Archean volcanic rocks can be compared. Further work by the committee will also focus on recommending suitable graphical displays for various volcanic suites, and a means of gauging the alteration of a given sample through comparison with typical Archean volcanic compositions.

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056. Geological Software for Personal Computers: An Update

E.J. Ambrose

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Precambrian Geology Section of the Ontario Geological Survey continues to develop and modify its collection of computer programs for use on IBM Personal Computers and compatibles. A list of the programs available prior to 1987 is given in Ambrose (1986). This year, four new programs have been added and two of the previously available programs have been modified.

NEW PROGRAMS

PGEPLOT

PGEPLOT draws three different plots of platinum group element (PGE) concentrations:

1. PGE concentrations recalculated to 100% sulphides divided by PGE chondrite abundances, following the method of Hoffman *et al.* (1979)
2. PGE concentrations divided by PGE chondrite abundances
3. PGE concentrations recalculated to 100% chromite divided by PGE chondrite abundances

Up to seven samples may be plotted on each diagram and each sample is represented by a different colour and symbol. A legend is produced defining the plotted symbols by sample numbers, comments, or both (Figure 056.1).

PLUNGR

PLUNGR rotates sedimentary crossbeds in plunging, folded strata, back to the original depositional position (assumed horizontal). This program is modified after PLUNGR (Parks 1974) and ROTATE (Parks 1970). The following statistical parameters are also calculated:

1. vector mean (a measure of central tendency)—the vector sum of the azimuths in the data set (Figure 056.2)
2. vector length (a measure of the azimuth consistency)—the length of the vector mean (Figure 056.2)
3. consistency ratio—the vector length divided by the number of observations
4. variance (a measure of the spread of the azimuths). A set of azimuths uniformly distributed around a circle has a variance of 10 800 (Griffiths and Rosenfeld 1953)
5. F ratio—the variance (10 800) of a uniformly distributed set of azimuths divided by the observed variance. The F ratio may be tested in F tables using one less than the number of observations

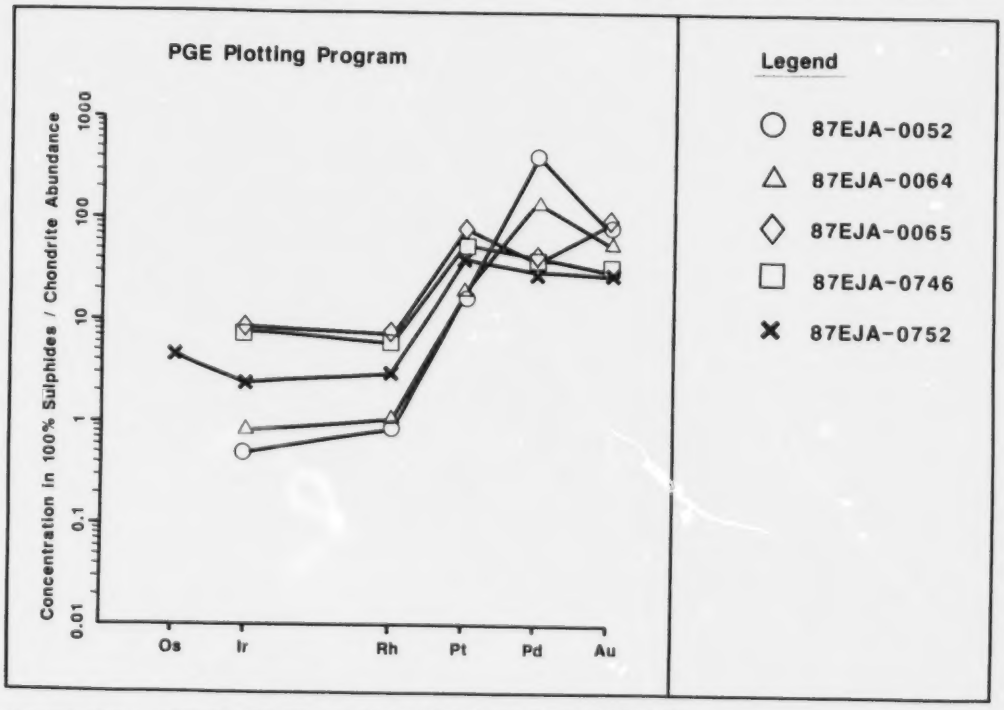

Figure 056.1. *Sample diagram produced by the program PGEPLOT.*

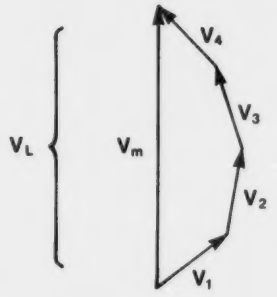

Figure 056.2. Graphical solution of the vector mean and the vector length: V_1 to V_4 are unit vectors drawn in the direction of the azimuths in the data set; V_m is the vector mean; V_L is the vector length.

as the degrees of freedom for the numerator and the denominator

The output generated by this program may be used with the stereonet plotting program (*see* STRNET in Ambrose (1986)) or the rose diagram plotting program (*see* ROSE below).

ROSE

ROSE draws circular frequency histograms of a set of azimuth measurements. This program is modified after ROSE (Parks 1974). The number of degrees per sector may either be selected arbitrarily or calculated based on the number of data points. The sectors may be centred around the vector mean (Figure 056.3a), centred around 000° (north) (Figure 056.3b), or start at 000° (north) (Figure 056.3c). The vector mean may be plotted as an arrow and the value printed on the diagram. The vector mean, vector length, consistency ratio, variance, and F ratio are also calculated (*see* PLUNGR above).

TRACEMOD

TRACEMOD models trace element fractionation during magmatic crystallization or partial melting based on the equations summarized by Arth (1976). Modal melting is assumed, that is, the proportion of the melt contributed by each phase is the same as its proportion in the solid. The nature of the liquid to be modeled may be chosen to be mafic, intermediate, or felsic. Up to 13 elements and 15 minerals may be included in the model. If rare earth elements are used, chondrite normalized diagrams may be generated.

The choice of models is:

1. perfect fractional crystallization—only the surface layer of the precipitated crystal is in equilibrium with the liquid (also known as Rayleigh or Surface Equilibrium Fractionation)
2. equilibrium fractional crystallization—the total crystallizing solid is in equilibrium with the liquid
3. batch melting—the melt and the solid are in continuous equilibrium until removal of the melt

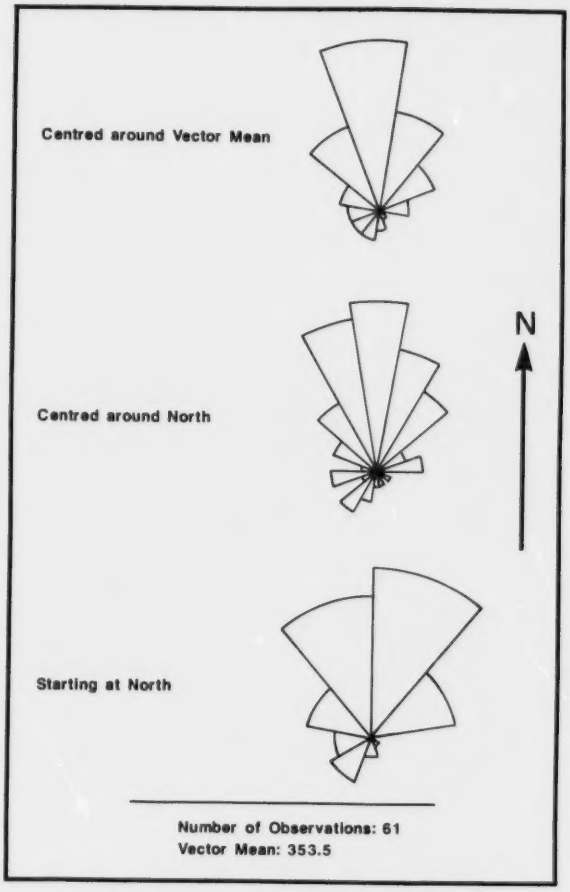

Figure 056.3. Sample diagrams produced by the program ROSE showing the different sector positioning: (a) 30° sectors centred around the vector mean; (b) 20° sectors centred around 000° (north); (c) 40° sectors starting at 000° (north), vector mean not plotted.

4. fractional melting—continuous removal of the melt from the residual solid
5. fractional melting plus mixing—continuous removal of the melt from the residual solid followed by collection of this melt in a single chamber

UPDATED PROGRAMS

Details of these programs are given in Ambrose (1986).

SAMPLOT

SAMPLOT plots sample locations on a UTM grid. There is now a choice of four scales: 1:250 000, 1:100 000, 1:50 000, and 1:15 840.

STRUCSYM

STRUCSYM plots structural symbols from a field-note file on a UTM grid at 1:100 000, 1:50 000, or 1:15 840 scale. Three additional structural features can now be plotted: veins, dikes, and younging direction.

SUMMARY

These programs were written in IBM Professional Fortran on an IBM-AT. They use an Industry Standard Plotting Package for Hewlett Packard 7220C and 7586B plotters. Source listings, User Guides, and Maintenance Guides are available for these programs by sending one diskette for every four programs requested (*see* address below). You will need a Fortran compiler and a plot library for your plotter/printer to execute these programs. Documentation of the field note system is also available.

Address enquiries and requests to:

Elizabeth Ambrose
Precambrian Geology Section
Ontario Geological Survey
Ministry of Northern Development and Mines
914—77 Grenville Street
Toronto, Ontario
M7A 1W4

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057. Remote Sensing of Mineral Target Areas: Two Examples from Eastern Ontario

J.S. Springer[1], V. Singhroy[2], and R.S. Mussakowski[3]

[1]Geologist, Northeastern Region, Ontario Ministry of Northern Development and Mines, Sudbury.

[2]Research Officer in Engineering, Ontario Centre for Remote Sensing, Ontario Ministry of Natural Resources, Toronto.

[3]Staff Scientist, Ontario Centre for Remote Sensing, Ontario Ministry of Natural Resources, Toronto.

INTRODUCTION

Remote sensing of ore bodies, which has been successful in barren bedrock landscapes, is more difficult in terranes where the surface expression of the ore bodies is diffused through cover materials. In this setting, the relationship between the captured image and what it represents on the ground is complex. In Ontario's mid-latitudes, for example, in areas where the bedrock is veneered with Pleistocene glacial debris beneath a vegetation cover, anomalies from bedrock ore bodies must be read through three layers of transposing media: overburden, soil, and biomass.

In much of the province, the surface that must be interpreted is the plant layer. This adds further difficulties to interpretation, including the degree of adjustment between soil and vegetation. Cut-over forest, secondary forest regrowth, and agricultural plantings obviously represent differing degrees of adjustment. Moreover, the physiology of plants, in extreme cases, enables them to exclude noxious elements, such as metals, and thus eliminate from the vegetation any visible anomalous response to the presence of an ore body.

As the interpretation of remote sensing images is so complex, careful, well-controlled case studies are needed to permit separation of the different influences. Studies designed primarily as field examinations are a good foundation to which a remote sensing component can be added, so that, over time, a range of empirical observations can be collected as a basis for a more general understanding of image-ground relationships.

This report presents preliminary results of the use of remote sensing in two localized examples in eastern Ontario. In the first case, narrow band, multispectral imagery, and infra-red colour photography were used to assist the targetting of Mississippi Valley-type lead-zinc-strontium veins. This work was a collaboration of J.S. Springer and V. Singhroy. In the second case, airborne colour photography, colour infrared photography, and thermal data were used to delineate an unconformity associated with the supergene enrichment of gold, iron, and copper. This work was a collaboration of J.S. Springer and R.S. Mussakowski.

STUDY 1: SPECTRAL VARIATION IN VEGETATION GROWING OVER LEAD–ZINC AND BARIUM–STRONTIUM VEINS

BACKGROUND

Renewed interest by Ontario producers of alkali metals in strontium ores has prompted re-examination of a suite of vein deposits in eastern Ontario. The veins cut rocks of Ordovician age and older. Remote sensing of spectral variation in the vegetation cover was selected as a method of search for unexposed veins because it potentially offers a means of rapidly scanning large areas for small targets that can be de-

LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

Figure 057.1. *Locations of test sites for study of spectral variation over mineralized veins.*

tected from the ground only by time-consuming search.

Ontario's strontium metal industry is centred close to Haley Station, near Renfrew in Eastern Ontario, where the Chromasco Division of Timminco Limited produces metallic magnesium, calcium, and strontium (Figure 057.1). Magnesium and calcium ores are obtained locally or from Canadian sources. However, the strontium feed stock is imported from offshore. Historically, eastern Ontario produced a small tonnage of celestite (strontium sulphate) from the Dempsey Lake vein deposit, located within 35 km of the Chromasco plant. Because local supplies of good quality strontium minerals would provide cost advantages to the manufacturing industry, a program of search for this commodity was begun in 1984.

Several studies have shown that vegetation which has been geochemically stressed may respond with changes in its spectral reflectance between 530 and 800 nm. These changes are manifested in:

1. the magnitude of the green reflectance at 550 nm (Labovitz *et al.* 1983; Singhroy 1985; Horler *et al.* 1983)
2. the magnitude of the 680 nm reflectance at the chlorophyll absorption region (Rock and Vogelman 1985; Singhroy *et al.* 1986)
3. the position and shape of the red reflectance edge from 680 to 800 nm (Horler *et al.* 1983; Hare *et al.* 1984; Collins *et al.* 1981; Singhroy 1985), and
4. changes in the magnitude of the infrared reflectance shoulder which occurs at various wavelengths greater than 780 nm (Rock and Vogelman 1985; Canney *et al.* 1979; Lyon 1975; Collins *et al.* 1981).

Although it was known that base metal contamination of soils cause a predictable shift of reflectance spectra in vegetation growing in these soils, the effect of strontium on the metabolism of the plants was not clear. It was, however, known that the strontium-bearing veins in eastern Ontario are geologically related to intersections of the post-Ordovician fault pattern and to the unconformity of the Paleozoic upon the Precambrian basement. Together, these geological characteristics defined broad target areas for search. Moreover, it was also known that the vein suite shows predictable patterns of mineral distribution related to upwarping of the basement. Some veins contain galena (lead) and sphalerite (zinc) with calcite, and others contain celestite (strontium) and barite (barium) with calcite. It was possible, therefore, to design a series of analytical steps which compared the reflectance of vegetation above known lead-zinc veins (from which a spectral shift could be expected) to the spectral signature from known strontium-barium veins. The known signatures of lead-zinc and strontium-barium could then be used to scan unknown areas, which were selected for search by geological reasoning.

GEOLOGICAL BACKGROUND

The celestite deposits are Mississippi Valley-type, open-space-filling veins, which cut Precambrian basement and Paleozoic cover rocks. They are part of a post-Ordovician fracture-controlled suite from which barite, fluorite, galena, and sphalerite have been mined at various times. Recent work (Williams 1982) has shown that the veins are related to faults and fractures of preferred orientation, and that the intersections of the faults and fractures commonly are nodes of deposition.

The veins are mineralogically zoned. This zonation appears to be related to basement doming. Sangster and Bourne (1982) pointed out an unusually high correlation of deposits with Precambrian marbles, and Carter (1984) showed a close spatial association of veins with the Precambrian-Paleozoic unconformity. Springer (1985) suggested that, although the final episode of vein deposition post-dates Ordovician limestones, porosity developed by karsting beneath the Precambrian unconformity, and differential porosities, both at the plane of unconformity and in the post-Cambrian rocks, have all influenced the path of migrating fluids and the sites of deposition.

Several features make these veins good candidates for remote sensing. Target areas can be constrained by known association with the fracture pattern or the plane of unconformity. Textural evidence from field observation shows that the veins have a vuggy, coarse-grained, crustiform texture (Spence 1922) with considerable brecciation, which causes them to weather in low relief. In some areas, the veins have been leached at the water table to form 10 to 12 m of loose, gravelly material. These features will influence the aerial appearance and both the types and vigour of the vegetation by reason of water availability.

Furthermore, most of the veins, even those that are largely composed of calcite, barite, and fluorite, have minor amounts of lead, zinc or copper. Base metals are known to produce a characteristic shift in spectra reflected from vegetation and this shift becomes more marked during drought or senescence. There is, therefore, reason to suppose that these veins will show changed reflectance at times of stress.

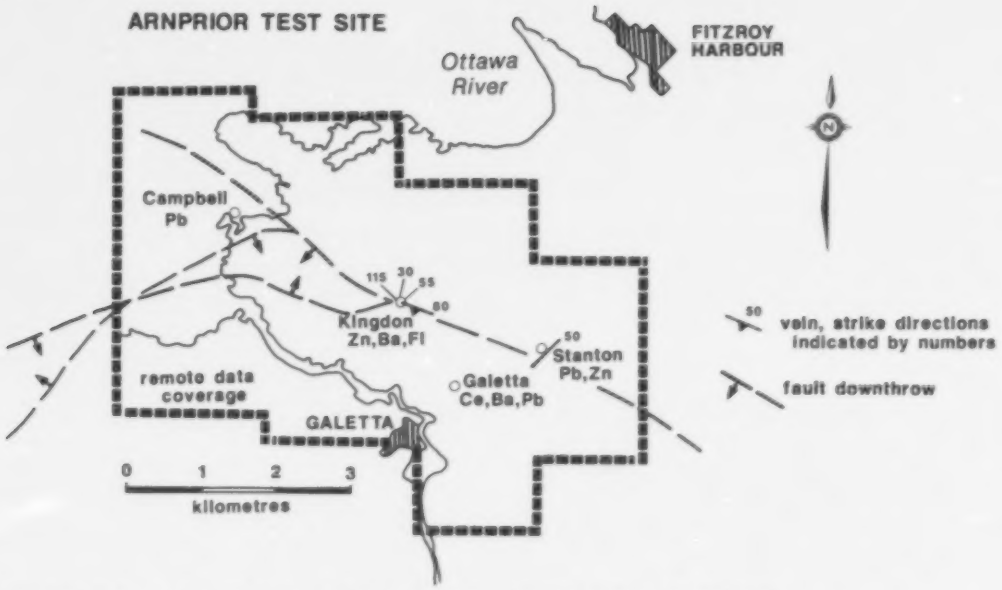

Figure 057.2. *Locations of faults and mineralized veins at the Arnprior test site.*

TARGET AREA SELECTION

At the start of the study, the spectral response of vegetation to soils rich in strontium was not known. A test patch was chosen, therefore, which would permit calibration of a site with base metal (lead-zinc) contamination against one with largely celestite-calcite (strontium) mineralization. At the Arnprior test site (Figure 057.2), three discrete veins with different mineralogy are grouped closely together. The Kingdon and Stanton veins respectively contain sphalerite, barite and fluorite in a calcite gangue, and galena in a calcite matrix. The Galetta vein contains celestite, barite and very minor galena in calcite. Since the veins are within 2 km of one another, they are all visible on a pair of adjacent aerial photographs. It was anticipated that, by comparing and contrasting the reflectance from vegetation on these three, it would be possible to establish a typical spectral signature which could then be used in unknown terranes.

Two other sites were chosen for remote data collection. The Dempsey Lake site, 35 km from Haley Station, produced small tonnages of barite-celestite in 1918 and 1941 from veins which contain celestite, barite, and calcite (Storey and Vos 1981). The Currie site, which is about 55 km from Haley Station and 15 m southeast of the Arnprior site, is mineralized with celestite-barite-calcite. Its importance is that it appears to be an isolated mineralizd vein in a terrain that is structurally very favourable for mineralization. The deposit is located at an intersection of two faults, and structural mapping by Williams *et al.* (1984) has shown many other such intersections to the west and south, which may be potential sites for mineralization.

At each site, remote data was collected from a sufficiently large area around the known vein to make variations in spectral reflectance, if such variation is indeed a characteristic of the mineralized site, readily observable in the surrounding, unknown terrains.

GEOLOGICAL GROUND CONTROL

The geological setting of both the target areas and the regional background was carefully documented. Descriptions of the three mineralized veins have been most recently completed by Williams (1982), who has also completed regional mapping of the post-Ordovician fault pattern and the resulting block displacements (Williams *et al.* 1984). Dominant regional fault sets strike at 105 and 125°. At their intersections, gash veins develop, commonly oriented 030 to 050°, which are locally mineralized with calcite ± fluorite ± galena ± sphalerite. The three known veins are close to the Paleozoic unconformity where Cambro-Ordovician rocks rest on the eroded Grenvillian rocks of Precambrian age. The veins are better developed in carbonate rocks either above or below the unconformity. There is a statistically greater correlation with Precambrian marbles, although cross-cutting relationships show that the mineralizing event is post-Ordovician in age. Initial control of soil geochemistry was provided by existing studies at regional and more detailed scales.

CONTROL ON VEGETATION COVER

This is an area of mixed conifers and hardwoods. Mining activity dates from before the First World War, at which time the veins were partly cleared. The regrowth of trees is, therefore, at least 30 to 40 years old and it is possible to collect vegetation from trees growing directly on the vein material. The less disturbed parts of the forest cover used as control are mainly covered with hardwoods. The dominant species include red oak (*Quercus rubra L*), white birch (*Betula papyrifera*), sugar maple (*Acer saccharum Marsh*) and trembling aspen (*Populus tremuloides*).

REMOTE DATA COLLECTED

Data, collected simultaneously on an airborne mission in early September, 1985, include:

1. colour infrared-photography at a scale of 1:15 000, for identifying vegetation types and selecting sites for field sampling, and
2. narrow band MEIS II (Multispectral Electro-optical Imaging Scanner) data with a spatial resolution of 4.2 m, at nanometer wavelengths of 680, 713, 753, and 798, using the geobotany filter set.

In addition, satellite data with a 30 m resolution from Thematic Mapping Missions TM3 and TM5, and thermal imagery with a 14 m resolution, are available.

The flight was scheduled for late August in the hope that stress, induced by drought or early wintering, would enhance the spectral shift at the edge between red and blue wave lengths.

FIELD SAMPLING

Initial reconnaissance field sampling was done in late August, 1985. Collections were made of one-year-old leaves and twigs from trees growing on trenches or tip heaps of mineralized material. Vegetation representative of background values was also collected. To examine the geochemistry of the foliage, 21 samples were taken from mature trees, estimated to be more than ten years old, growing directly on mineralized rock piles. Background samples were chosen from trees growing on unmineralized bedrock, or on bedrock covered with only 1 to 2 m of glacial debris, such that the root system could reasonably be assumed to have reached bedrock.

To narrow the range of variation, only the dominant species at a site were sampled. Leaf material was collected from white birch, white cedar, trembling aspen, hemlock, and white ash.

Samples were also collected, at the same time, for ground measurements of spectral reflectance of the foliage. First-year leaves were taken from the outer branches and the crowns from a total of 25 trees. Laboratory spectral reflectance measurements were made on the leaves within five hours of gathering them.

To determine metal contents of the mineralized bedrock, samples from the old workings and gangue material from immediately adjacent tip heaps were collected for whole rock analysis. In 1986, a suite of bedrock samples to represent background values was collected.

LABORATORY EXAMINATION

For investigation of the foliage chemistry, air-dried leaf material was ashed and made up to standard solutions for qualitative ICP (Inductively Coupled Plasma) spectrometry. The elements analyzed for included aluminum, barium, beryllium, calcium, cerium, chromium, cobalt, copper, iron, lanthanum, lead, magnesium, manganese, molybdenum, nickel, niobium, neodymium, phosphorous, strontium, tantalum, titanium, tungsten, vanadium, yttrium, zinc and zirconium. Rock samples were subjected to partial analysis for lead, zinc, barium, fluorine, gallium, germanium, and silver. All of these elements are known to be present in, or might be expected from, Mississippi Valley-type deposits.

PRELIMINARY ANALYTICAL RESULTS

Tables 057.1 and 057.2 show values of zinc, copper, strontium, and barium in various species from the five sites. Table 057.3 lists assay values from vein materials and comparative data from a suite of local marble bedrock. From preliminary examination, base metals appear to accumulate in leaf ash to levels or ranges that are typical for a given element in a given species. In cedar, for example, copper runs 3 to 5 ppm; zinc, however, is ten times as much at 40 to 70 ppm. In hemlock, the corresponding values are 4 to 6 ppm copper and 80 to 140 ppm zinc. Zinc appears to accumulate more readily in birch than in other species; elevated zinc values are present in birch leaves from the Stanton and Kingdon deposits, where sphalerite is recorded. For the alkali metals, strontium and barium, similar relationships are seen. Barium values in all species are one to two orders of magnitude lower than strontium values (2 to 20 ppm barium; 20 to 2500 ppm strontium). Although all species show strontium enrichment at localities mineralized with celestite (Dempsey, Galetta, Kingdon), cedar shows the greatest enrichment.

Laboratory spectral measurements on the trembling aspen and white birch at the Kingdon Vein site showed a 10 to 20% increase in reflectance at the infrared plateau, indicating that these species were under geochemical stress. Less than a 5% increase in reflectance was observed from oak and sugar maple leaves at the same near-infrared region. Only the oak leaves exhibited signs of chlorosis, from a 5% increase in reflectance in the 400 to 700 nm range. No "blue shift" at the red reflectance edge was observed in the four species examined.

MEIS II image enhancements, involving a combination of the first and second principal components and vegetation index combinations of the 713 and 753 nm bands, permitted identification of high reflectance from stressed trembling aspen and white birch in the vicinity of the mine sites.

CONCLUSIONS

1. The enhancement of selected bands of MEIS II data can permit the identification of spectral responses associated with metal stress in vegetation, if the following conditions are met:
   i. The laboratory or airborne spectral response of species growing on both mineralized and "background" sites must be known. This information is essential for selecting MEIS II bands that will be specific to tree species and type of soil mineralization within a single study site.
   ii. Since the selection of MEIS II bands is based on the results of laboratory spectral response tests, the field sampling procedure must be consistent and the laboratory reflectance measurement procedure must be standardized.
2. The level and type of mineralization greatly influence spectral response in the visible and near-

TABLE 057.1. ASSAY VALUES IN PPM FOR ZINC, COPPER IN LEAF ASH BY SPECIES PER LOCALITY.

	W. Birch	Ash	W. Cedar	Hemlock	T. Aspen
ZINC					
Dempsey	193.60	-	41.42	100.80	-
Currie	-	-	38.19	86.60	-
Stanton	301.80	-	42.06		(229.20, 313.60, 291.00)
Galetta	645.50	-	67.79	139.00	-
Kingdon	(1626.00, 2064.00)	93.95	-	-	(1954.00, 2463.00)
Kingdon (background)	787.20	32.38	-	-	947.10
COPPER					
Dempsey	6.16	-	3.16	5.92	-
Currie	-	-	4.81	4.07	-
Stanton	9.84	-	4.34		(10.00, 20.26, 12.66)
Galetta	8.21		3.75	4.50	
Kingdon	4.60 3.20	26.19	-	-	7.94 7.54
Kingdon (background)	3.93	66.30	-	-	7.38

TABLE 057.2. ASSAY VALUES IN PPM FOR STRONTIUM, BARIUM IN LEAF ASH BY SPECIES PER LOCALITY.

	W. Birch	Ash	W. Cedar	Hemlock	T. Aspen
STRONTIUM					
Dempsey	1269.0	-	2857.0	466.4	-
Currie	-	-	32.4	19.30	-
Stanton	13.08	-	11.05	-	(24.53, 25.97, 18.46)
Galetta	520.10	-	823.40	335.70	-
Kingdon	(217.20, 118.40)	66.87	-	-	(427.10, 445.80)
Kingdon (background)	16.48	20.62	-	-	35.44
BARIUM					
Dempsey	14.92	-	20.30	1.63	-
Currie	-	-	2.47	2.59	-
Stanton	5.72	-	10.53	-	(4.82, 5.08, 3.77)
Galetta	9.91	-	6.42	2.22	-
Kingdon	(5.79, 2.80)	7.27	-	-	(6.23, 2.38)
Kingdon (background)	2.20	3.16	-	-	1.99

TABLE 057.3. ANALYSES FOR SELECTED ELEMENTS OF BEDROCK AND VEIN MATERIAL.

MINERALIZED SAMPLES, VEIN MATERIAL

		Ga	Cs	Pb	Zn	Ba	F	Ag	
					All Values in ppm				
KINGDON	1		<5	<3	1490	106	130	190	
	2		<5	<3	1600	9050	280	280	
GALETTA	1		<5	<3	10	22	210	430	
	2		<5	<3	27	49	280	1040	
STANTON	1		<5	<3	<10	129	710	1100	
	2		<5	<3	17	30	820	300	
CURRIE	1		<5	32	<10	<5	25.5%	250	
	2		<5	18	<10	<5	20.8%	160	
DEMPSEY	1		33	<3	<10	<5	5.9%	70	
	2		<5	<3	16	<5	4530	120	
BACKGROUND VALUES IN GRENVILLE MARBLES, KINGDON SITE									
86-01			<5	<3	<10	11	130	740	<2
86-02			<5	<3	<10	12	150	1200	<2
86-05			<5	<3	<10	<5	120	370	<2
86-06			13	<3	27	40	1450	80	<2
86-07			14	<3	<10	100	3000	270	<2
86-08			<5	<3	<10	22	110	380	<2
86-09			<5	<3	<10	<5	180	740	<2
86-10			<5	<3	<10	6	120	540	<2
86-11			<5	<3	<10	16	210	1600	<2
86-12			<5	<3	<10	9	150	1080	<2
86-13G			<5	<3	<10	6	130	370	<2
86-14			<5	<3	<10	14	310	1350	<2
86-15			<5	<3	<10	12	320	3280	<2
86-16			<5	<3	12	<5	150	1070	<2
86-17			<5	<3	11	<5	120	460	<2
PALEOZOIC DOLOMITE ABOVE UNCONFORMITY, KINGDON SITE									
86-03			<5	<3	<10	<5	120	120	<2

infrared regions. Where the sulphide values were less than 1500 ppm, as in the case of the Arnprior test sites, the only spectral change that occurred was in the magnitude of the infrared plateau. The stress in the deciduous species was more pronounced than that in the coniferous species indicating that deciduous trees are sensitive to lower levels of soil mineralization.

3. Geochemical stress in vegetation is site specific and subtle. In this study, small areas of mineralization (no larger than 60 m^2) were observed from enhanced MEIS II data, but not from enhanced LANDSAT TM imagery. For the study of relatively small mineralized sites, therefore, airborne, narrow-band, high resolution, multispectral scanner images are recommended.
4. Geochemical bedrock anomalies are locally expressed as higher element values in leaf ash. The levels reached show the combined influence of the amount of element available, and the physiological tolerance of individual species. White birch and trembling aspen appear to collect zinc; strontium is absorbed by all species, but more particularly by white cedar.

CONTINUING WORK

During the 1987 field season, increasing emphasis has been placed on standardizing and focusing the study. Hence, the Currie Mine site has been deleted from the study because the host rock is Paleozoic limestone, whereas the others are hosted by Precambrian marble.

Increasingly, work has concentrated on the Kingdon Mine site as a baseline study. The site has been geologically mapped at 1:3 000 scale, using low level colour aerial photographs as a base (D.A. Williams, Geologist, Ontario Ministry of Northern Development and Mines, Tweed, personal communication, 1986). Two further series of ground spectral measurements have been obtained in 1986 and 1987 from mineralized and control areas. The 1987 measurements are tied to two 50 by 50 m grids from which soil and leaf samples have been collected. Observations have been made on slope variation and aspect, as these are reported (Hornsby and Bruce 1987) to affect spectral appearance, and statistics have been obtained of forest composition, density and growth parameters.

Lastly, the Arnprior (Kingdon, Stanton, Galetta group) and the Dempsey Lake sites were flown in July 1987, using the Programmable Multispectral Imager (formerly the Fluorescence Line Imager), developed by Moniteq Limited. It is hoped that use of another sensor system for vegetation reflectance will yield a comparative data set. The flight was scheduled for earlier in the year than the previous flight, so as to evaluate the effects of senescence on the reflectance values.

STUDY 2: THERMAL EXPRESSION OF A MINERALIZED UNCONFORMITY

INTRODUCTION

The search for economic mineralization in the Grenville Province has shown that occurrences of iron oxide ochres and supergene gold mineralization are locally concentrated within a zone of oxidation at the Precambrian-Paleozoic unconformity. At the unconformity, the Grenvillian basement is overlain by an unmetamorphosed cover in which the main Paleozoic transgression is well marked by fossiliferous, Middle Ordovician carbonate rocks.

The plane of unconformity dips gently to the south and has a hilly paleotopography that is too fine to be mapped at 25 ft contour intervals. Reddening of soils, due to oxidation of iron, is commonly a good indicator of the erosion plane. The partly pre-Paleozoic age of this reaction is shown by sharp changes in iron content across the plane, and by a basal Paleozoic sequence which includes fragments of reddened Precambrian lithologies.

In the Madoc-Marmora area, coarse granular gold, derived from Grenvillian sulphide mineralization and concentrated by supergene enrichment below the unconformity, has been reworked into the basal Paleozoic grit and, locally, into glacial (Pleistocene) or younger stream sediments. The Precambrian-Paleozoic unconformity is, however, the foremost horizon of secondary concentration and is, therefore, an important mapping target.

Several factors make the exhumed unconformity surface difficult to trace in three dimensions. Firstly, while glaciation has removed overlying patches of the slabby Paleozoic carbonates, the surface of the Precambrian rock is still masked by a thin layer of Paleozoic basal grit or glacial debris. There are, furthermore, considerable differences in elevation across the Precambrian surface, owing both to the original Precambrian topography and to subsequent block faulting. Detailed surface mapping of the unconformity (Springer 1985; Di Prisco 1986) has helped to trace its position in ground exposures. Thompson (1985) and Williams and Thompson (1986) have used shallow seismic refraction and detailed lithostratigraphic correlation on local fault structures to infer the elevation of the unconformity in individual fault blocks.

For this study, direct field observation and low-level colour aerial photography were used to trace the reddened outcrop of the erosion surface, and an image map of thermal data from an existing LANDSAT 4 TM scene was generated. The latter showed unexpected anomalies which gave indirect indication of the unconformity under shallow cover.

STUDY AREA SELECTION

The study is centred on Madoc Township in southeastern Ontario, and covers an area of approximately 300 km^2 (Figure 057.3). Physiographically, the area is divided into two parts by the Paleozoic-Precambrian contact that runs along the southern side of Moira Lake. The area north of Moira Lake forms part of the Precambrian peneplane, which slopes gently southward. The area south of Moira Lake is underlain by

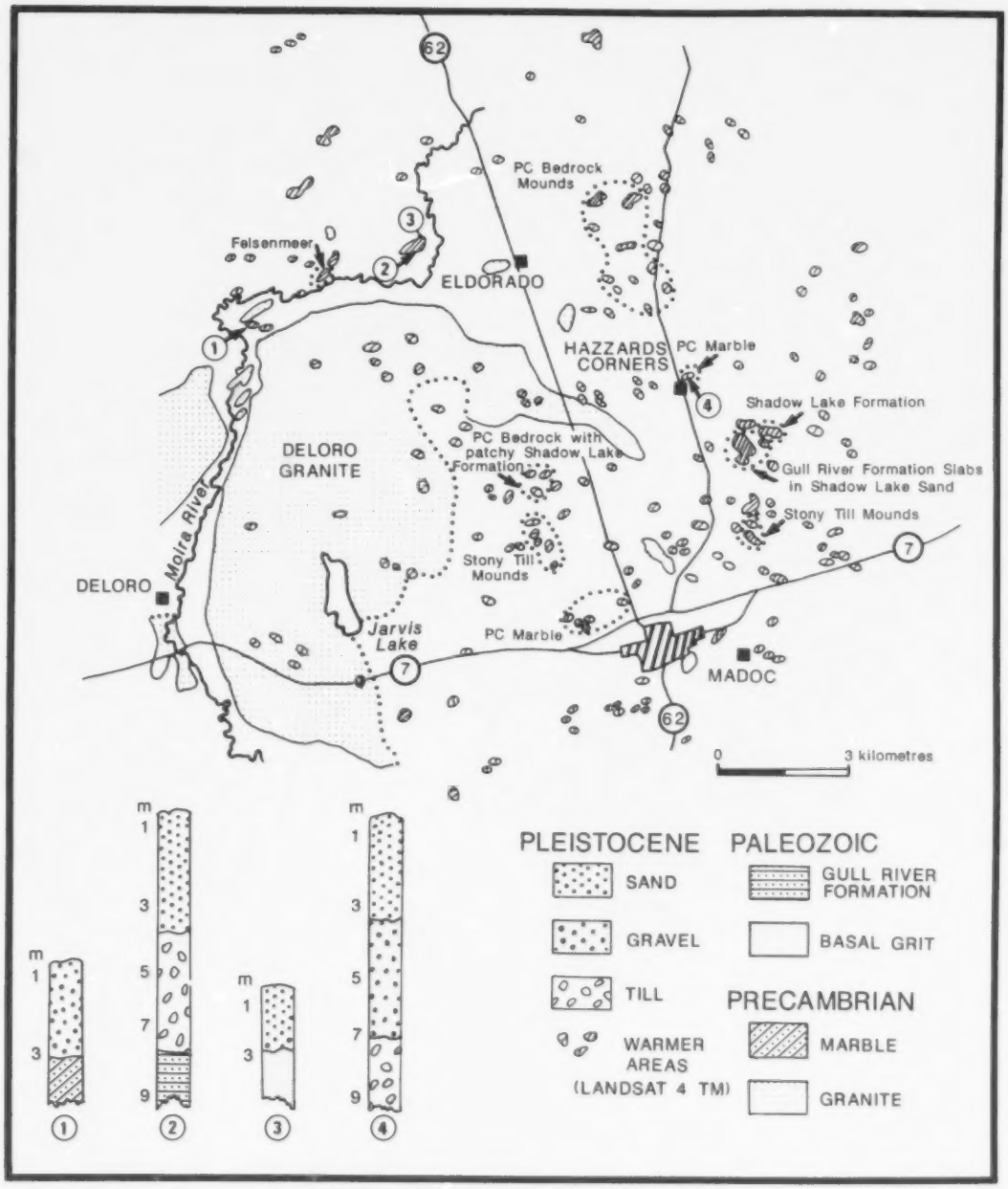

Figure 057.3. *Location of LANDSAT TM thermal anomalies in Madoc Township, and profiles through selected thermal anomalies. Profiles reconstructed from shallow seismic and drill data (ground data from L.G.D. Thompson, geophysicist, Ontario Ministry of Northern Development and Mines, Tweed, personal communication, 1986).*

flat-lying Paleozoic limestones of the Lake Ontario Homocline.

The northwestern corner of Madoc Township is a rough, rocky upland, which marks the exhumed Precambrian peneplane sloping southwards beneath the Paleozoic cover. The western area is a rocky highland of hills of the Deloro granite pluton. Near the centre of the township, flat highland areas are underlain by outliers of nearly horizontal Paleozoic carbonate rocks. The present terrain has been levelled by glaciation, which smoothed upstanding bedrock and filled topographic lows. Recent shallow seismic surveys (Thompson 1985; Williams and Thompson 1986) have shown a considerable variation in the subsurface elevation of the Precambrian peneplane

due to the combination of paleotopography and post-Paleozoic faulting. The downside of the fault structures commonly shows a wedge of glacial debris above the Paleozoic bedrock.

On many Precambrian rocks, very little soil material remains; on the Paleozoic rocks, soils up to 10 m in depth have formed from the calcareous, basal sandstone units. Small, Pleistocene glacial sand and gravel deposits are scattered across the township. As the surficial deposits are thin, the topography for the area reflects the topography of the Precambrian and Paleozoic rock surfaces. Although the terrain of the study area is, in general, quite rough, the relief rarely exceeds 70 m.

The Paleozoic outliers are covered with extensive areas of good farmland, whereas the Precambrian rocks are covered by forests. Most of the farmland consists of rough pasture, with only a small proportion used for growing crops. Within the forested area, sugar maple is the dominant species on well-drained sites, while cedar occupies the wetter sites.

PREPARATION OF THE LANDSAT TM THERMAL IMAGERY

LANDSAT TM records thermal imagery in the 10.5 to 12.5 μm range, with a ground resolution of 120 by 120 m. The image used in this study was recorded during a southbound, daytime orbit on October 24, 1983 (Track 16, Frame 29, Quadrant 1) at 10:18 local time. The sun azimuth was approximately 153°, and the sun elevation, 30°. It was one of the few digital TM data sets available for Ontario when the study began.

Raw image data was registered to the UTM grid system through standard geometric correction procedures, and the original pixels were resampled from 30 to 25 m. Bands 2 and 3 were used for selecting ground control points because of the low resolution and generally poor contrast of the thermal band. A linear contrast stretch was performed on the thermal data to enhance the contrast between minimum and maximum values.

To view the thermal imagery, grey tones are normally produced representing relative radiant temperatures. For this investigation, a colour output product was created by superimposing the positive of the thermal image, printed in red, on the negative of the same image, printed in green.

The resulting enhancement presented cool areas in green (the coolest in dark green) and warm areas in red (the warmest in bright red). Anomalous areas were level-sliced and manually plotted onto a 1:50 000 scale topographic map. The colour enhancement of the thermal band, the overlay map of anomalies, and a simulated true-colour infrared enhancement of TM bands 1, 2 and 3 were used in interpreting the thermal data, together with aerial photographs and ground verification. As part of the overall geological investigation of the study site, cores of surficial materials and seismic refraction readings were taken as well.

INTERPRETATION OF THE LANDSAT TM THERMAL DATA

Daytime thermal imagery records relative radiant temperatures resulting from solar heating. By considering the different effects produced by solar heating on various surface and near-surface materials, an interpreter can correlate a warm or cool area in the image with a specific ground location, and form a hypothesis as to the type of material responsible for the thermal signature.

In the present study, temperature variations occurring within the Precambrian Shield (the forested part of the study area) resulted primarily from differential solar heating and shadowing. Bedrock ridges and valleys, useful in delineating geological structure, were enhanced. Evidence of these features was also visible on the true-colour image, particularly in the northwestern area of the site, where foliation or bedding within Precambrian metavolcanic rocks was evident, and in the southwestern part of the study area, within the Deloro granite pluton.

The most striking correlation between temperature and surface materials, however, was the correspondence between large, warm (red) areas and agricultural lands, and between cooler (green) areas and forested lands.

Thermal anomalies (or "hot spots") occurred across the study area, but were found in greater concentration on the agricultural land. The anomalies in the area underlain by Precambrian rocks generally occurred over outcrops. Outcrops at the study site ranged in size from 50 to 200 m^2. A few were discernible on the original true-colour image while the rest were verified or identified from available aerial photography and field observation. The thermal anomalies on the agricultural land occurred in open fields (either fallow or pasture), apparently unrelated to vegetation cover type.

The locations of virtually all of the 190 thermal anomalies were examined stereoscopically on available aerial photographs, and 30 were studied on-site. Although the terrain varied considerably from one location to another, the anomalies were easily located in the field, as each proved indicative of a distinct feature or condition.

The sites of most of the anomalies are characterized by a slight topographic rise, or knoll, discernible on aerial photographs, but having no apparent significance in the field. A few of the sites were strewn with surface rubble or boulders, likely brought to the surface by repeated cultivation. Some sites had angular surface features, such as small ridges or patches of exposed bedrock. Finally, a few sites appeared to have no surface features which might give rise to thermal anomalies. The sum total of this evidence suggests that most of the anomalies indicate areas where bedrock is either exposed or in close proximity to the surface.

The remaining anomalies indicated the presence of bouldery till on well-drained esker patches. Although some features, such as drumlins, had greater topographic relief than the areas of thermal anomalies, they did not produce a distinct thermal signature.

All anomalies or thermal patterns that did not result from differences in solar heating related to topography, likely resulted from the inherent thermal properties of the material from which the thermal response was received. To understand the reasons behind each response required a consideration of the conditions in effect at the time of the image recording.

When the images were recorded, radiant temperatures were rising rapidly. Dense materials, such as rock, have a high thermal inertia (a measure of responsiveness to temperature change). Exposed outcrops, therefore, would be expected to register as "hot spots". Soil materials, on the other hand, have a lower thermal inertia and are thus somewhat less affected by diurnal temperature changes.

Over the agricultural areas on the imagery, soils appeared relatively warm, likely due to their higher thermal capacity, that is, the ability to store heat over a few days of relatively warm weather. The thinner soils over the Precambrian bedrock, in contrast, appeared relatively cool.

Watson and Hummer-Miller (1984) made similar observations on satellite Heat Capability Mapping Mission (HCMM) data of an area in Utah. He noted that low thermal inertia was recorded in areas of low elevation covered with surficial deposits and overgrown with scrub vegetation. High thermal inertia, on the other hand, was recorded in areas of higher elevation where bedrock was exposed at the surface and the vegetation consisted of dense coniferous and deciduous forest. Watson's results demonstrated that imaged thermal inertia could express the difference between unconsolidated material and bedrock.

Vegetation on the Precambrian Shield area of the present study site was predominantly deciduous. At the time of imaging (October 24), most of the leaves had fallen from the trees. The leaves probably had little or no influence on the thermal response from the site. The coolest areas on the thermal image corresponded to areas of coniferous vegetation, represented on the true colour imagery in dark green. It is likely that the cooling effect resulted from forest transpiration.

It was hypothesised that the "hot spots" in the agricultural areas indicated dry areas resulting from the presence of bedrock or coarse aggregate materials close to the surface. Better drainage in this thin soil layer would produce a warmer thermal signature. In poorly drained areas, on the other hand, evaporation from most soils would lower the surface temperature.

Auger sampling and seismic refraction has been done over a few of the thermal anomalies since the recognition of the value of thermal imagery. This work has also indicated near-surface bedrock as a cause of the anomalies. Figure 057.3 shows stratigraphic profiles for these sites and identifies the surface materials of sample sites.

APPLICATION OF THERMAL ANOMALIES TO THE MADOC STUDY AREA

It appears that thermal imagery may provide an important first step in locating target areas for seismic verification of depth to bedrock, and that this type of imagery helps to reveal underlying structure that would otherwise be invisible. In this case, thermal anomalies have helped in clarifying variation in the basal Paleozoic outliers, and in achieving a closer delineation of the surface of the Precambrian unconformity, which is locally the key horizon for paleoplacers and mineral concentration.

CONCLUSIONS

The following conclusions can be drawn from the Madoc Township thermal TM study:

1. Thermal patterns reflecting the differential solar heating of topographic features are useful for the delineation of bedrock structure.
2. Thermal patterns in the study area, caused by differences in the thermal inertia of surface materials, are useful in delineating unconsolidated materials from Precambrian bedrock.
3. LANDSAT TM thermal data can help plan field investigations by indicating areas of exposed bedrock, and areas where bedrock is near the surface, to make auger sampling and seismic surveys easier and more effective.
4. Thermal clues to the proximity of bedrock to the surface provide information on bedrock topography which might not be available from other sources.
5. Thermal anomalies indicating the presence of buried aggregate materials may prove helpful in exploring for such deposits, especially in areas with a thick layer of overburden, where the bedrock is unlikely to influence the thermal signatures.

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ENGINEERING AND TERRAIN GEOLOGY PROGRAMS

058. Summary of Activities of the Engineering and Terrain Geology Section, 1987

Owen L. White

Section Chief, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

In 1987, the staff of the Engineering and Terrain Geology Section were engaged in field investigations in twelve areas across the Province, five in northern Ontario and seven in southern Ontario. In six of these twelve areas, field parties operated under the Canada Ontario Mineral Development Agreement (COMDA).

The Quaternary Geology Subsection was responsible for the greater part of the field activity with six field parties located from Fort Frances to Toronto. A. Bajc continued his mapping of the Fort Frances-Rainy River area. This area contains tills and their associated proglacial deposits from both the Laurentide ice and the Keewatin ice. Ice-contact deposits associated with Laurentide ice are numerous but scattered. Ice-marginal deposits associated with Keewatin ice are not common in the map area. Lacustrine sands, silts and clays associated with the Emerson Phase of glacial Lake Agassiz overlie both noncalcareous Laurentide ice drift and calcareous Keewatin ice drift. Overburden drilling programmes to elucidate the regional stratigraphy and assist overburden exploration programmes are planned for the Fall of 1987 and again in 1988. Several boreholes are to be sited along reflection seismic profiles run during the 1987 field season by staff of the Geological Survey of Canada.

F. Kristjansson and L. Thorleifson have almost completed the mapping of six map areas at a scale of 1:50 000 in the Beardmore-Geraldton area. To supplement the surface mapping a programme of sonic drilling to elucidate the stratigraphy was planned for the Fall of 1987. Field investigations suggest four till units are present, making the stratigraphy remarkably similar to that identified in the Hemlo area. The oldest till, a gritty silty sand till, occurs as a thin, discontinuous unit directly overlying the bedrock and, as the clasts are of local provenance, the authors indicate that this till is the best material to sample in a drift exploration programme. This oldest till is overlain by a fine-grained calcareous till (with two possible facies) which appears to be the dominant till of the area and up to 52 m thick. Another gritty, sand till overlies older tills as a thin, discontinuous veneer especially in the central portion of the area. Glaciofluvial ice-contact deposits are well represented in the area. Glaciolacustrine deposits are widespread and range in texture from a silty fine sand to silty clay and may, in fact, be related to the waters occupying the Nipigon Basin.

P.W. Alcock continued the mapping of the Shining Tree area by the extension of field activities to the Sinclair Lake (NTS 41P/14) map area. This area lies in the west-central portion of the Abitibi Belt of the Superior Province. Only one till has been identified in the area to this time, its matrix and clasts reflecting local metamorphic and metavolcanic rock types. The sampling of till sites for the establishment of a geochemical data base resulted in 98 samples being collected in 1987. Down ice from known gold occurrences, gold grains were evident in the sand size fraction and anomalous gold chemical values were found in the silt and clay fractions of some of the samples. The till is up to 4 m thick over the project area but total drift thickness can be up to 50 m, especially in the central and southwestern portions of the map area. Here a wide variety of ice-contact, outwash, lacustrine and eolian landforms are found.

Along the eastern shore of Georgian Bay, P. Kor continued mapping in five map sheet areas adjacent to those mapped in 1986. As in that year, much of the area mapped in 1987 was characterized by thin or bare bedrock, especially west of the CNR tracks. The thickest deposits of drift were found in valleys, especially those oriented perpendicular to the direction of flow of the late Wisconsinan ice. Boulder concentrations were numerous throughout the area suggesting that much till was removed after glaciation by the waters of glacial lakes Algonquin and Nipissing. Ice-contact and glaciofluvial deposits are few and far between but glaciolacustrine valley fill materials and fine sediment rhythmites are widespread. These deposits are concentrated in depressions and valleys throughout the map areas particularly near Magnetawan and south of Orrville. Organic remains found near Skerryvore are probably related to the Nipissing transgression.

P. Karrow completed the mapping of the Brampton area by extending the previous work into the more densely populated urban areas in the eastern parts of the map sheet. Stratigraphic sections were examined in the Etobicoke Creek and the Humber River valleys. In the southern part of the area mapped, the drift is quite thin and several new "pop-ups", indicative of high horizontal *in-situ* stresses in the bedrock, were identified. The major material identified at the surface is the silty Halton Till, except south of the Iroquois bluff where fine sand deposited in Lake Iroquois forms the Iroquois Plain. Shale is quarried for brick manufacture at Streetsville and Cooksville but sand and gravel extraction has ceased in the map area. Most former pits are rehabilitated and the sites used for housing. Data collected for the Urban Geotechnical Data Bank Program will be used to develop drift thickness and bedrock topography maps.

In the Metropolitan Toronto area, R. Kelly described and sampled bank sections in the valleys of the Humber and the Don Rivers and in the West Duffins and Little Rouge Creeks. This was done in order to provide more "third dimension" information for the data bank in the Toronto area.

In the past year, the Aggregate Assessment Office continued the preparation of aggregate resources inventories in both northern and southern Ontario. On St. Joseph Island and adjoining areas on the mainland, 15 townships were investigated and assessed by M. Gauvreau and R. Gorman who identified adequate resources for most purposes in all but two of the townships visited. Nevertheless, the occurrence in the local deposits of Huronian Supergroup rocks from the bedrock suggests that aggregate which is intended for use in heavy duty concrete should be checked for its potential alkali reactivity before use.

In the Parry Sound-French River area, G. Jones and C. Cameron investigated the aggregate resources potential in 15 townships flanking Highway 69. Over the whole area, aggregate resources are neither plentiful nor of a high quality. Sand deposits which are more readily available in the south often contain excessive amounts of fines. Coarse gravel is very scarce and is usually supplied from local bedrock quarries, but the gravel that is available in the northern part of the area contains rock types from the Huronian Supergroup and has the potential to be alkali-reactive if used in concrete manufacture.

The sand and gravel resources in five townships on the Bruce Peninsula are reported by M. Gauvreau as limited except in Amabel Township where locally significant deposits occur. Over most of the area investigated drift deposits are fairly thin, therefore the underlying dolostones of the Guelph and the Amabel Formations could provide an adequate resource of crushed stone.

The rocks of the Eramosa Member and the Wiarton/Colpoy Bay Member of the Amabel Formation are presently extracted on the Bruce Peninsula for building and decorative stone and the potential for further development of these and other units led to the decision to map in more detail the Paleozoic rocks of the Peninsula. Derek Armstrong, in reporting this activity, notes the stratigraphic discrepancies which have arisen over the years, reports new outcrops of the economically useful Eramosa Member, and notes the present and potential economic resources of the Paleozoic rocks of the area.

On Quinte Island (Prince Edward County), G. McFall reports detailed field investigations of the Paleozoic rocks of the area as part of a multiagency investigation of neotectonics in eastern Canada. Lineaments and other features identified from conventional air photography and other remotely sensed data have been field checked to establish their origins and to determine, if possible, evidence for any neotectonic activity.

J.R. Meadows and C.R. Fouts report that building stone potential also has been the focus of attention in the Muskoka-Parry Sound area. Studies have been done at all active building stone quarries in the area to cover geological and structural aspects of the stone and, in addition, to document quarry and masonry techniques used in the production of dimension stone.

059. Quaternary Geology of the Fort Frances Area

A.F. Bajc

Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

Quaternary mapping of the Fort Frances-Rainy River area began during the summer of 1986. Mapping of the Rainy River area was undertaken during the first summer (Bajc and Gray 1987) and continued to the east this past field season. The area mapped during the 1987 field season is bounded on the north by the 49th parallel of Latitude and the international border to the south. The western boundary follows the 94th parallel of Longitude and the eastern boundary is delimited by the shore of Rainy Lake and 93°30′W Longitude. The map area includes the Northwest Bay (52 C/13), Emo (52 C/12), and parts of the Fort Frances (52 C/11) and Mainville Lake (52 C/14) National Topographic System (NTS) map sheets. The project is designed to establish the stratigraphy thereby assisting mineral exploration and aggregate resources evaluation. An overburden drilling program is planned as follow-up and will commence during the fall of 1987.

Highways 11 and 71 traverse the study area and form the main transportation corridors in the region. Access throughout much of the remaining area is provided by secondary highways, township, concession, and forestry access roads, as well as water access along Rainy River, Rainy Lake, and many interconnecting lakes to the north.

Several investigations related to Quaternary geology have been undertaken within the study area. Earlier studies include a surficial geology and soil study within the Rainy River District by Johnston (1915) and a reconnaissance soil survey undertaken by Hills and Morwick (1944).

More recent reports related to surficial geology, and terrain and aggregate resource evaluation, include those of Zoltai (1961, 1965), Roed (1980), and the Ontario Geological Survey (1983). Detailed soil studies of the area were conducted by the Ontario Institute of Pedology (1984). Peatland evaluation and resource inventories were undertaken by Graham and Tibbetts (1965) and more recently by Northland Associates (1984). A pilot survey was undertaken by the Minnesota Geological Survey in the Emo area to test geochemical responses of soil, till, and stream sediments in areas of known mineralization (Ojakangas, Meineke, and Listerud 1977).

BEDROCK GEOLOGY

Bedrock geology mapping programs covering most of the map area were conducted by several authors over the past three decades. Initially, mapping of the Emo area was undertaken by Fletcher and Irvine (1955). The Fort Frances area to the east and the Off Lake-Burditt Lake area to the north were later mapped by Davies (1973) and Blackburn (1976), respectively. A simplified bedrock geology map of the entire area is also depicted in a geological compilation series map produced by Blackburn (1979).

Limited outcrop within the southern half of the map area has resulted in a simplified conception of the bedrock geology whereas the northern half is, to a large extent, better understood. The geology of the southern half has been inferred primarily from widely scattered outcrops, geophysical interpretation, and exploration drillholes.

LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

A wide variety of bedrock lithologies have been recognized within the map area. The western half is transected by a southwesterly trending pile of mafic to felsic metavolcanic rock with somewhat fewer metasedimentary rocks, including banded iron formation and mafic intrusive rocks. The eastern half of the map area consists primarily of felsic to intermediate intrusive rocks of the Rainy Lake Batholith, with smaller amounts of mafic volcanic rocks and metasediments to the south. Of primary economic interest are areas transected by the westerly extensions of the Quetico and Seine River faults, the Off Lake-Burditt Lake supracrustal belt, and the mafic intrusions located in the southern half of the map.

QUATERNARY GEOLOGY

The study area has been affected by two major ice advances originating from two markedly different centres of outflow. An early strong advance from the Labradorean ice centre to the northeast is crosscut by a later, weaker advance from the Keewatin centre to the west. Striation data to support the latter is minimal and may be attributed to a thin, lobate ice sheet during the advance and a lack of hard striating lithologies at the base of the glacier. Evidence of this easterly advance is based primarily on pebble fabric measurements and the compositional nature of the sediments themselves. Reference is made by Zoltai (1961) to a late glacial readvance of the Labradorean ice sheet into the northern part of the map area. Evidence to support this hypothesis may be documented in the stratigraphic sequences encountered this past field season. Striations of this advance are indistinguishable from those of the earlier Labradorean lobe advance.

Thicknesses of glacial and nonglacial deposits are highly variable in the study area. The mapped area can be subdivided into two contrasting terrain types based on drift thickness alone. The northern half of the map area contains abundant outcrop with localized pockets of thick drift, whereas the southern half contains sporadic outcrop with overburden thicknesses commonly in excess of 30 m and in places as great as 60 m.

The oldest drift sheet recognized was deposited by the Labradorean sector of the Laurentide ice sheet. These sediments are exposed on surface over much of the area northeast of a line drawn between the city of Fort Frances and Little Pine Lake which is situated on Highway 71. Thin deposits of slightly calcareous to noncalcareous, dense, silty sand till were occasionally encountered on the stoss sides of rock knobs. More commonly, thicker deposits of loose, stoney, substratified flow and meltout tills were found on the leesides of rock knobs. Pebble counts from these two facies suggest local to semilocal provenance.

Deposits of ice-contact stratified drift associated with the retreating Labradorean ice sheet are found scattered on the surface throughout much of the northern half of the map area. The largest deposits are concentrated along a northwest-southeast trending belt which traverses the map area between Fort Frances and the northwestern corner of the map area. This belt appears to represent a recessional or stillstand position of the retreating Labradorean ice sheet and is referred to as the Rainy Lake-Lake of the Woods Moraine by Zoltai (1961).

Drift of the Labradorean lobe extends southwards beneath thick deposits of younger sediments as confirmed by gravel pit exposures and borehole information.

Either synchronously with or shortly following the retreat of the Labradorean ice from the map area, a suite of calcareous tills, glaciolacustrine sediments, and related deposits were laid down in a proglacial lacustrine environment by Keewatin ice flowing from the west. Compact deposits of gritty and pebbly silty clay to clayey silt till occurs over much of the map area southwest of the Rainy Lake-Lake of the Woods Moraine. Rhythmically laminated silts and clays and varieties of waterlain till are encountered both above and below as well as within the calcareous till sequence. Pebble counts from all facies of this till sheet suggest a distal origin. Up to 80% of the lithologies are derived from the Phanerozoic succession of rocks that occur in south-central Manitoba nearly 200 km due west.

Ice-marginal deposits associated with the terminal position of the Keewatin ice are not common in the map area. The most notable of these are located in the Couchiching Indian Reserve, 3 km north of Fort Frances; 4 km west of Wasaw Lake; and 3 km northwest of Little Pine Lake. These ice-marginal deposits occur in the form of ice-contact stratified drift, ice-contact deltas, and kettled glaciolacustrine deposits, respectively.

Deposits of strongly to slightly calcareous glaciolacustrine silts and clays are found in low areas beyond the limits of the carbonate (Keewatin) till package. Dilution of the glaciolacustrine sediments with noncalcareous sediment can be attributed to a proximal Labradorean sediment source and has resulted in a whole suite of carbonate contents in the lacustrine deposits.

Northeast of the Rainy Lake-Lake of the Woods Moraine, the author has documented the occurrence of a noncalcareous silty clay to silt till, that seldom exceeds 1 m in thickness and often overlies noncalcareous glaciolacustrine sediment. The till often contains inclusions of glaciolacustrine sediment, is stone-poor, and is always found in local depressions. Zoltai (1961) reported a similar till sheet around Sioux Narrows and along the eastern shore of Lake of the Woods in his reconnaissance survey of northwestern Ontario and suggested a late glacial readvance of the Labradorean ice sheet to the Rainy Lake-Lake of the Woods Moraine. The author has documented noncalcareous outwash overlying calcareous clay till southwest of the Rainy Lake-Lake of the Woods Moraine but has not encountered a noncalcareous silty sand till northeast of the moraine. Further work is necessary to establish whether the noncalcareous clay till is a separate, younger till sheet or simply a lateral facies equivalent of the older, noncalcareous silty sand till.

Below the elevation of 350 m above sea level and often overlying either the calcareous or noncalcareous drift packages, one encounters lacustrine sands, silts, and clays which were deposited during

the Emerson Phase of Lake Agassiz. A distinctive band of red clay, which is common to much of the eastern Lake Agassiz basin, has been documented in the map area as well. Organic remains are commonly found within and below Emerson Phase sediments. Two wood samples collected from an exposure on the Rainy River just east of the mouth of the LaVallee River and from a position stratigraphically below Emerson Phase lacustrine sediments were radiocarbon dated at 10 400 and 10 100 years before present. These dates are in agreement with the chronology adapted for the remainder of the Lake Agassiz basin.

Beach and nearshore deposits associated with the Emerson Phase are found throughout the map area at around 350 m above sea level. These sands and gravels rarely exceed 3 m in thickness, are usually strongly calcareous, and often contain fossil mollusc remains.

Extensive peatlands reaching maximum thicknesses of 8 or 9 m occur over much of the southern half of the study area. Smaller, more restricted deposits occur in isolated topographic lows over much of the northern part of the map area.

ECONOMIC GEOLOGY, FOLLOWUP PROGRAMS, AND RELATED RESEARCH

An overburden drilling program is commencing during the fall of 1987 aimed at establishing a stratigraphic framework for mineral exploration in the area. Approximately 25 boreholes are planned across the Fort Frances-Rainy River area with additional boreholes planned for the summer of 1988. The main objectives of the program are to intersect and sample the lower Labradorean-derived till sheet and test previously unexplored areas in terms of their mineral potential. The boreholes have been located in zones of high mineral potential such as along the Quetico and Seine River faults as well as near aeromagnetic anomalies.

A Geological Survey of Canada reflection seismic program was undertaken in the map area during the summer of 1987 and was aimed at testing the area in terms of its suitability for this geophysical technique as well as to provide information on the subsurface stratigraphy along selected lines of interest. The technique has been successful in the Val Gagne area of northeastern Ontario where reflection seismics have been used to locate thick accumulations of till beneath lacustrine clays for drift prospecting purposes (Pullan *et al.* 1987). Preliminary results from the Fort Frances-Rainy River study seem to suggest that this technique may have excellent potential for delineating stratigraphy in the subsurface. Several boreholes are planned by the Ontario Geological Survey along the reflection seismic profiles to test the usefulness of the technique in this area.

A bedrock geology mapping program was undertaken by G.W. Johns of the Ontario Geological Survey in the adjoining Rainy River area during the first half of the 1987 field season (Johns, this volume). Jennifer McKay is undertaking a B.Sc. Thesis at the University of Western Ontario and will be describing the nature of the upper, Keewatin-derived till sheet at six selected sites transecting the Fort Frances-Rainy River area. Special emphasis will be placed on the physical and chemical properties of the till sheet and their relationship to provenance and mode of deposition.

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060. Quaternary Geology of the Beardmore–Geraldton Area, District of Thunder Bay

F.J. Kristjansson[1], **and L.H. Thorleifson**[2]

[1]Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto

[2]Research Scientist, Terrain Sciences Division, Geological Survey of Canada, Ottawa.

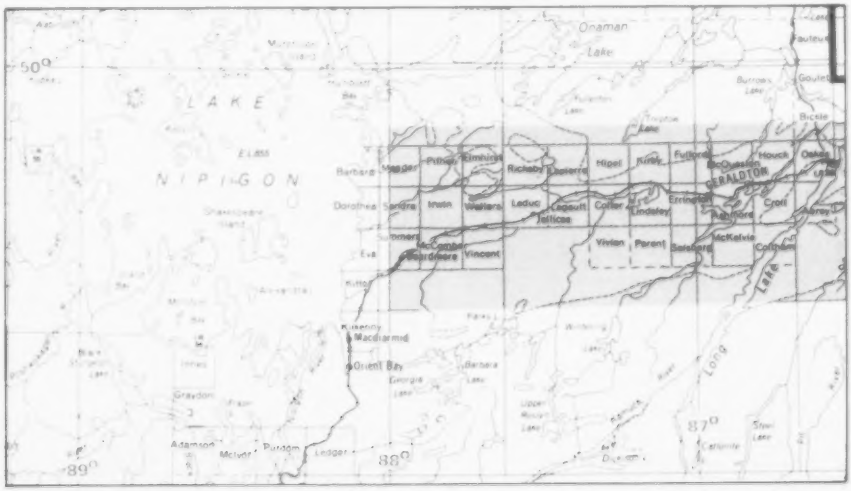
This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

A program of detailed Quaternary geological mapping at a scale of 1:50 000 was initiated in the Beardmore-Geraldton area in 1986 (Kristjansson 1986). The primary objective was to provide a Quaternary geology database designed to facilitate programs of drift prospecting and aggregate exploration. In 1986, mapping of the Geraldton and Wildgoose Lake (42E/10 and 42E/11 NTS map sheets Part A) was completed. During the 1987 field season, the Beardmore, Longlac, Treptow Lake, and North Wind Lake (42E/12, 42E/15 south half, 42E/14 south half, and 42E/13 south half NTS map sheets respectively, Part B) were completed. The study area, for the purpose of further comment and discussion, includes both the area investigated in 1986 and the area surveyed this field season.

BEDROCK GEOLOGY

The study area is underlain predominantly by bedrock of early Precambrian age. The northern and southern parts of the study area are underlain by bedrock of the Wabigoon Subprovince and the Quetico Subprovince, respectively. In the Beardmore-Geraldton area, the Wabigoon Subprovince has been subdivided into two greenstone belts: (a) the Onaman-Tashota Belt; and (b) the Beardmore-Geraldton Belt. The Onaman-Tashota Belt can be described as a predominantly intermediate to felsic volcanic assemblage, intruded by a number of felsic plutonic bodies. The Beardmore-Geraldton Belt, which is situated immediately to the south of the Onaman-Tashota Belt, is a predominantly metasedimentary sequence intercalated with mafic to intermediate metavolcanic rocks. A variety of small- to intermediate-scale felsic and mafic plutonic bodies are associated with this



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

greenstone belt. The Onaman-Tashota Belt is separated from the Beardmore-Geraldton Belt by the prominent, east-west trending Paint Lake Fault. The Quetico Subprovince in the study area is represented by a thick and extensive metasedimentary-migmatitic rock sequence, which is flanked on the southern side by felsic intrusive and metamorphic rocks. Both Wabigoon and Quetico Subprovince rocks were intruded during the late Precambrian by an extensive system of north-trending diabase dikes and, in the extreme west part of the study area, relatively large, tabular, diabase sills.

The Onaman-Tashota Volcanic-Plutonic Belt and the Beardmore-Geraldton Metasedimentary-Metavolcanic Belt are currently the focus of intense mineral exploration efforts. Both have a high potential for gold and base metal deposits (Pye *et al.* 1966; Mason and White 1986).

QUATERNARY GEOLOGY

Ice direction features, primarily glacial striae, indicate a glacial advance to the south and a more recent glacial advance to the southwest. Evidence of the early advance is rare. Planar, erosional facets with striations trending about 190° azimuth have been observed on bedrock surfaces in a number of locations in the study area. The preservation of such facets, which are considered to be remnant of an early phase of bedrock streamlining to the south, is due to glacier flow separation in the leeside of bedrock obstacles during the later episode of ice flow. During the last glacial advance, the bedrock surface was reoriented and streamlined in a southwest direction. Bedrock drumlins, bedrock stoss, and lee features and whaleback forms, with long axes oriented south-southwest to west, are a common feature of bedrock terrains in the study area. Glacial striae of the latter glacial phase exhibit a diverging or radial flow pattern. In the eastern part of the study area, striation trends of 200° to 210° azimuth were observed. Glacial striae examined in the central part of the study area trend about 220° to 240° azimuth. Glacial striations measured in the western part of the study area indicate glacier flow trends of 240° to 255° azimuth. Exceptions to this pattern include a number of apparently anomalous crosscutting striation relationships (e.g. 240° intersecting 220°, 230° intersecting 210°, 220° intersecting 240°, 190° intersecting 220°...).

Although terrain characterized by negligible drift (i.e. Bedrock-Dominated Terrain) or by thin and/or discontinuous drift (i.e. Bedrock-Drift Complex) may be observed to some extent throughout the study area, such terrain types form major areal units only within the Geraldton-Longlac and Beardmore-North Wind Lake map areas. The Wildgoose-Treptow Lake map area, on the other hand, is characterized by a thick and extensive drift sheet. Within bedrock-dominated terrain, areas of major bedrock exposure (>75 percent) in association with minor, thin drift and/or colluvium can be expected. Minor to moderate exposures of bedrock, associated with a thin and/or discontinuous drift and colluvial cover, can be expected in bedrock-drift complex. Generally, the drift thickness is thin (<1.0 m), but locally can be as thick as 2.0 to 3.0 m. It is important to note that bedrock occurs at, or very near, the ground surface in units of bedrock-drift complex. Consequently, it can be stated that the geometry of the bedrock surface strongly influences the morphology of the ground surface in this terrain type.

On the basis of texture, structure, lithology, and geotechnical criteria, four varieties of till were observed in the Beardmore-Geraldton area:

1. gritty, silty sand till
2. dense, gritty, silt till
3. loose, gritty, sandy silt till, and
4. clast-rich, gritty, sand till.

The gritty, silty sand till occurs throughout the study area as a thin, discontinuous sheet immediately overlying bedrock. The till can be quite compact and in section often exhibits a weakly-developed fissile structure. An abundance of clasts exhibiting well-developed stoss and lee features suggests that deposition at the base of sliding glacier ice prevailed during accretion of this till. The clast composition of this till variety is dominated by rock types of local provenance. The gravel fraction from some till samples, collected in areas underlain by Archean metavolcanic-metasedimentary bedrock, exhibited greater than 80 percent angular-subangular clasts composed of local rock types. Striation measurements from bedrock underlying the gritty, silty sand till indicate that this till variety may be entirely related to the later glacial phase in the Beardmore-Geraldton area.

Gritty, silty sand till is considered to represent the basal part of the Beardmore-Geraldton till sequence. There are several reasons for this:

1. Gritty, silty sand till was always observed immediately overlying bedrock.
2. The similarities between the till varieties described in the Beardmore-Geraldton area and the till types which make up the Hemlo till sequence are remarkable. It is a gritty, silty sand till which occupies the basal part of the Hemlo sequence.
3. A reverse circulation program conducted by Cominco Limited in the vicinity of Turkey Lake established the presence of a local till immediately overlying bedrock, but underlying a substantial thickness of fine-grained, calcareous till (Kristjansson *in* Patterson *et al.* 1984).

A fine-grained calcareous till, which can be subdivided into a lower, dense, gritty, silt facies and an upper, loose, gritty, sandy silt facies, appears to form the dominant till of the study area. In the Wildgoose-Treptow Lake map sheet in particular, fine-grained, calcareous till forms a thick, laterally extensive sheet. The authors, during a sonic drill program conducted this past field season, documented calcareous till thicknesses up to 52 m. The surface morphology of the till sheet is characterized by a marked lineation parallel to glacier flow. These features exhibit an exceptionally high length to width ratio and, perhaps, should be referred to as drumlinoidal ridges. The long axes of these features, south and southwest of Wildgoose Lake, trend about 230° to 240°. The integrity of fine-grained calcareous till throughout the

study area in terms of texture, percentage carbonate, clast composition and apparent absence of local lithologies is noteworthy. Geddes *et al.* (1985), in the Hemlo area, made similar observations and indicated that such characteristics can be attributed to englacial transport over long distances. Geddes *et al.* also noted a correlation between the presence of fine-grained, calcareous till and large scale, leeside depositional environments. Hicock (1986a), in a study of the processes responsible for the deposition of fine-grained carbonate till in the Hemlo area, describes a mechanism whereby the englacial load under dynamic ice conditions can be transferred to the glacial bed in the leeside of upland settings. The mechanism provides a means by which the accretion of considerable thicknesses of non-local till can occur. Both the observations of Geddes *et al.* and the depositional mechanism proposed by Hicock may be directly applicable to the Beardmore-Geraldton area. Regardless, it is evident that during late Wisconsinan time an exceptionally large volume of fine-grained, calcareous sediment was entrained in the Hudson-James Bay Lowland and transported across a long distance of Precambrian Shield terrain. This material was deposited as a fine-grained, carbonate till upon the Canadian Shield at least as far south as the Beardmore-Geraldton area.

A clast-rich, gritty, sand till occurs as a thin, discontinuous veneer overlying bedrock or fine-grained, calcareous till. It was observed in the southeast part of the Beardmore-North Wind Lake map area, the southwest, north-central and northeast parts of the Wildgoose-Treptow Lake map area, and the northwest part of the Geraldton-Longlac map area. Local rock types appear to comprise a substantial component of the lithology of this till. The fact that this till variety was observed overlying non-local, carbonate till is of interest. There appears to be a strong relationship between the presence of clast-rich, gritty, sand till and bedrock-dominated upland areas. In the Beardmore-Geraldton area, uplands tend to be underlain by coarse, crystalline, plutonic rock types (e.g. granite or granodiorite). The upland areas probably triggered the leeside depositional mechanism proposed by Hicock. The formation of clast-rich, gritty, sand till probably represents both the latest glacial activity in the study area and a period of enhanced meltout sedimentation which may be related to the development of a compressive flow regime. The marginal area of the wasting ice sheet is considered to have been quite thin. During periods of severe climate, freezing conditions possibly penetrated the ice column freezing the marginal area of the glacier to its bed. The transition from normal or extending flow under wet-based conditions to compressive flow under frozen-bed conditions would result. Bedrock-dominated upland areas may have been most affected by such a transition because ice thicknesses would be thinnest over these locations. Glacier margins frozen to their beds represented barriers to subsequent wet-based flow from upglacier areas. This could have resulted in the generation of great compressive forces in the marginal area of the ablating ice mass. Debris frozen to the base of the glacier, within such a stress system, may have been thrust high into the ice column. This material, following a short-lived period of downglacier transport prior to stagnation, eventually underwent meltout and was deposited upon both bedrock and nonlocal, carbonate till in the leeside setting.

Glaciofluvial ice-contact and glaciofluvial outwash sediments are well represented in the study area. Major esker-kame complexes, which trend south-southwest to southwest across the study area, form prominent landform-sediment systems in both the Geraldton-Longlac and the Wildgoose-Treptow Lake map areas. There appears to be a strong relationship between the presence of such landform-sediment systems and lowland areas. Glaciofluvial outwash sediments occur in abundance in the west-central part of the Wildgoose-Treptow Lake map area, and in southwest to west trending valley systems in the Beardmore-North Wind Lake map area. These sediments represent a major meltwater system which, as depicted by Zoltai (1965), flowed north along the present day course of the Namewaminikan River and then west-southwest along lowlands presently occupied by the Blackwater River, the Beatty, Pasha and Windigokan Lake system, and the Namewaminikan River.

The predominance of glaciofluvial ice-contact as opposed to glaciofluvial outwash sediments, especially in the Geraldton-Longlac and Wildgoose-Treptow Lake map areas, is noteworthy. The morphology of glaciofluvial terrains in these map areas generally can be described as mildly to markedly hummock- and ridge-form. The association of extensively kettled areas also was commonly observed. The prevalence of ice-contact landforms and sediments and the absence of end moraines marking long-term equilibrium positions in the study area appears to imply rapid deglaciation. Whereas traditional concepts of rapid ice retreat have been based on ideas of regional stagnation, the authors favour a model of stagnation-zone retreat (Koteff 1975). The ablating ice mass is conceived of as having systematically melted back across the study area by shedding a narrow belt of ice along its margin. The stagnant/active ice interface in such a glacier system is thought to have shifted upglacier in increments, perhaps annual. In the process a narrow belt of stagnant glacier ice, upon and against which meltwater sediments were deposited, was left behind. The diameter of some residual ice depressions is large (e.g. 300 to 500 m). These dimensions can perhaps be utilized to infer the width of the marginal stagnant zone.

Glaciolacustrine sediments in the study area range in texture from silty, fine sand and sandy silt to clayey silt and silty clay. These sediments were observed with some frequency in lowland settings adjacent to the larger lake basins. Rhythmically-laminated clayey silt and silty clay was observed in the vicinity of North Wind Lake situated in the northwest part of the Beardmore-North Wind Lake map area. Abundant silty, fine sand and sandy silt was observed in many of the southwest- to west-trending valley systems situated in this area. These sediments very likely represent the extension of a high level lake stage, which occupied the Nipigon basin during deglaciation of the study area, into these lowland areas. Following the drainage of these high level lake stages, areas of glaciolacustrine sand were often extensively re-

worked by eolian activity. Dune forms were frequently observed within areas of glaciolacustrine sand. In the Beardmore-North Wind Lake map area, fine-grained, glaciolacustrine sediments have been observed at elevations as high as 1075 ft above sea level. In the Geraldton-Longlac map area, rhythmically-laminated clayey silt and silty clay occurs in abundance in the vicinity of the Kenogamisis Lake and Long Lake basins (Kristjanssson 1986). A glaciolacustrine sand plain, which occurs to the west of Geraldton and which extends into the Wildgoose-Treptow Lake map area, has been extensively reworked by eolian activity. Well-developed dune forms may be observed in this part of the study area.

Organic deposits occur generally as thin (1 to 2 m), continuous veneers overlying relatively impermeable substrates such as till or fine-grained glaciolacustrine sediment. Relatively extensive deposits of organics may be observed in the south-central and east-central parts of the Wildgoose-Treptow Lake map area, and in the north-central and west-central parts of the Geraldton-Longlac map sheet. A reconnaissance peatland survey with detailed site investigation has been completed for the Ontario Geological Survey by Dendron Resources Surveys (1986).

Alluvial sediments, present in contemporary flood plain environments, or preserved in the form of early Holocene terraces, form only a minor part of the Quaternary geology of the study area.

SYNTHESIS

The Beardmore-Geraldton area exhibits an array of exceptionally well-preserved subglacial and ice marginal features. The bedrock surface has been glacially streamlined to a marked degree. The strongly lineated character of the thick and extensive till plain, and the high length to width ratio of the drumlinoidal ridges, is striking. A lack of burial by proglacial sediments has provided an excellent opportunity to examine a subglacial landscape reflecting the character of the ice mass responsible for its formation.

Generalizations, which appear to be valid within the study area and which appear to imply a relatively thin, late Wisconsinan ice mass, are as follows:

1. The model of marginal frozen bed conditions invoked to explain the presence of local, meltout till over nonlocal, carbonate till implies a relatively thin glacier marginal area.
2. The spatial relationship between esker systems and lowlands reflects low hydraulic gradients at the time of esker construction, which in turn suggests a relatively thin late Wisconsinan ice mass.
3. The predominance of ice-contact landforms and sediments and the absence of end moraines marking long term equilibrium positions suggests rapid marginal meltback, which is best accommodated by the presence of a relatively thin ice mass.

The authors suggest that the late Wisconsinan ice mass in the Beardmore-Geraldton area was characterized with a low, or lower, profile than has traditionally been considered acceptable for Precambrian Shield terrain. Certainly, notions of a relatively thin late Wisconsinan ice mass are consistent with a lower longitudinal profile. At any rate, it may be that during latest glaciation of the Precambrian Shield the late Wisconsinan ice mass exhibited a lower profile because of high ablation rates and the generation of abundant subglacial meltwater. In this case, late Wisconsinan ice in the Beardmore-Geraldton area merely reflected the lower profile in general of glacier ice on the Precambrian Shield. Although the authors do not reject such an idea, they prefer to consider an alternative.

Hicock (1968b) proposed that many of the landforms and sediments of the Beardmore-Geraldton area are explicable with reference to the phenomenon of ice streaming. In this regard, the authors have made a number of observations which are characteristic of, and possibly unique to, ice streams:

1. The diverging or radial pattern of late phase glacial striae might reflect the radial flow pattern documented from contemporary ice streams.
2. The complex, and apparently anomalous, pattern of crosscutting striations can be produced by melting back the marginal area of the ice stream, superimposing its unconfined radial flow pattern upon parallel striae sets representing the confined flow of the ice stream. This represents an alternative to invoking changes in source area or separate episodes of glaciation to explain such patterns.
3. The considerable thickness and lateral extent of non-local, fine-grained, carbonate till indicates an exceptionally high sediment flux, which is perhaps best explained as a function of high debris concentrations and rapid glacier flow.
4. The geometry of the area bounding thick, fine-grained, carbonate till dispersion in the Beardmore-Geraldton area may be described as linear, plume-like and parallel to glacial flow. The plume, of which the long axis appears to be centered over the Geraldton area, bears definite similarities to the Boothia-type plume attributed by Dyke (1984) to ice streaming in high latitude areas of the Laurentide ice mass.

Recently, Hicock and the authors of this report (Hicock *et al.*, in preparation) considered the glaciological implications of thick and extensive deposits of fine-grained till on the Canadian Shield. It was concluded that the Laurentide ice mass due to the presence of such a substrate possibly exhibited a much lower profile on Precambrian Shield terrain than has previously been considered acceptable. Hence, the possibility that the Beardmore-Geraldton area was an area of rapid, low profile ice flow during the late Wisconsinan should not be discounted. The authors prefer a model of ice streaming due to the implication of a relatively thin, rapid flowing ice mass capable of a large volume of erosional and depositional work. The fact that many seemingly disparate observations appear relatable and coherent within the spatial and temporal framework provided by the concept of ice streaming reflects the utility of the model for the Beardmore-Geraldton area.

APPLIED QUATERNARY GEOLOGY

Till represents a prime geochemical sampling medium for mineral exploration in areas of glaciated terrain dominated by a thick and extensive drift sheet. An important objective of the field program was to investigate in detail the lithological, mineralogical and geochemical characteristics, sedimentology and stratigraphy of the varieties of till present in the study area. The 400 till samples collected over the course of both the 1986 and 1987 field seasons have been submitted for laboratory analysis. In addition to routine analyses of grain size and percentage carbonate, heavy mineral separations are being subjected to trace element geochemistry (e.g. Au, As, Sb, B, Cu, Zn, Pb, Ag, plus 28 additional elements). Although the results of these analyses are not yet available, a number of field observations of immediate significance to programs of mineral exploration are apparent.

A thick, generally continuous sheet of till was documented in the vicinity of, and to the south and southwest of Turkey Lake and Wildgoose Lake. The till sheet in part overlies a portion of the Beardmore-Geraldton Metavolcanic-Metasedimentary Belt. The thickness of the till sheet, up to 60 m (Thorleifson and Kristjansson, in preparation), represents a distinct impediment to conventional programs of mineral exploration. The lithology of the gritty, silty sand till appears to be dominated by rock types of local provenance. The fact that this till was encountered quite frequently during field work this past summer, at least in areas peripheral to and away from the area of thick, fine-grained, calcareous till, suggests that there has been good glacial dispersion of the local bedrock. More importantly, such observations suggest that there has been good preservation of the gritty, silty sand till. This till variety probably represents an excellent sampling medium for till geochemistry programs. The rock types characteristically found in the fine-grained, calcareous till varieties generally are derived from distant source areas. The presence of abundant, fine-grained, calcareous till, due to its obvious distant-source composition, very likely represents a constraining factor with respect to till geochemistry programs. Till sampling techniques which provide for both deep sampling and accurate till identification are required.

Although the authors are confident of their assessment of the till stratigraphy for the Beardmore-Geraldton area, and of the validity of statements regarding the preservation of the prime till geochemistry sampling horizon; nevertheless, they are aware of the need for a more substantial subsurface database. Towards this end a 14-hole sonic drill program, funded by the Geological Survey of Canada (Thorleifson and Kristjansson, in preparation) was completed within the area of the thick till cover. The results, when available, should provide an adequate subsurface database from which a definitive statement regarding the Beardmore-Geraldton till stratigraphy can be made.

The planning and development of municipal works and mining operations requires knowledge of, and access to, the aggregate resources of the area. The potential for the discovery of substantial quantities of gravel in those parts of the study area mapped as glaciofluvial ice-contact and outwash deposits is high.

Glaciofluvial gravel deposits in the Beardmore-Geraldton area characteristically exhibit relatively high percentages of Paleozoic sedimentary rock. Consequently, the presence of deleterious lithologies, such as chert, and the potential for silica-alkali reactivity problems relative to the manufacture of concrete products must be considered.

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061. Quaternary Geology of the Shining Tree Area, Districts of Sudbury and Timiskaming

P.W. Alcock

Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

The project area is bounded by Latitudes 47°30′ N and 48°00′ N and Longitudes 81°00′ W and 81°30′ W. It includes two 1:50 000 scale map sheets: Shining Tree (NTS 41 P/11) and Sinclair Lake (NTS 41P/14). Highways 560, 566 and 144 are the main transportation corridors in the region. The Grassy Lake and Wicks secondary roads serve the central and northeastern portions of the project area. Numerous logging, fire access and mineral exploration roads as well as the lake and river systems provide good access to most of the remaining areas.

The objectives of this project are to determine the distribution and stratigraphy of the Quaternary sediments and to expand the geological database of the area for mineral exploration, forestry, and aggregate planning.

Quaternary geological mapping at a scale of 1:50 000, reconnaissance surficial till sampling, and overburden trenching have been undertaken on the Shining Tree map area by Finamore (1986) and on the Sinclair Lake map area by the author.

Previous reconnaissance Quaternary geological studies in the project area were completed by Boissonneau (1965, 1968) and Roed and Hallett (1979a, 1979b). Detailed bedrock and overburden geochemical investigations were completed by Closs and Sado (1982) in the Midlothian Lake and Natal Lake areas which are included in Sinclair Lake and Shining Tree map sheets.

BEDROCK GEOLOGY

The project area lies within the west-central part of the Abitibi Belt of the Superior Province.

The bedrock geology of the Shining Tree map area was mapped by Carter (1981). Early Precambrian rocks comprise a metavolcanic-metasedimentary sequence, mafic and felsic plutonic rocks and diabase dikes. Middle Precambrian rocks include clastic and chemical sedimentary rocks of the Quirke Lake and Cobalt Groups and intrusive Nipissing diabase sills. Early to Late Precambrian diabase dikes cut all formations (Carter 1981).

The bedrock geology of the northern portion of the Sinclair Lake map sheet was mapped by Bright (1970, 1984). Early Precambrian rocks comprise a metavolcanic sequence with subordinate units of iron formation and metasediments. Mafic and ultramafic sills and sill complexes intrude the metavolcanic sequence. During later regional east-west folding, the northwestern portion of the map area was intruded by a granitic pluton. Late porphyritic monzonite, granodiorite and syenite stocks were emplaced in the metavolcanic succession. Early to Late Precambrian diabase dikes cut the previously emplaced units (Bright 1970, 1984).

Deposits and occurrences of gold, silver, cobalt, copper, zinc, lead, molybdenum, nickel, iron, and asbestos occur in the project area (Carter 1981; Bright 1970, 1984).

LOCATION MAP Scale : 1:1 584 000 or 1 inch to 25 miles

QUATERNARY GEOLOGY

The area investigated contains a sequence of Quaternary sediments representing the last major, late Wisconsinan ice advance over the region.

Glacially streamlined and striated bedrock forms, till fabrics and dispersion trends of lithologic indicators demonstrate that the last dominant ice movement was from the north towards 180°± 30°azimuth in the Sinclair Lake map sheet. Minor late-glacial shifts in ice direction due to bedrock topographic influences are indicated by a few examples of 160°- 180°-striations cross-cutting an earlier set of 140°- 160°-striations. No clear evidence was found of an earlier ice advance to the southwest similar to that documented by Veillette (1986) in the Timmins, Matheson and Lake Temiskaming areas. Certain roches moutonnées preserve facets or remnants of grooves oriented southwest-northeast on the lee sides but these are not definite indications of former ice advances.

Drift thicknesses in the project area range from less than 1 m to more than 50 m. Within the Sinclair Lake map sheet, the central and southwestern portions commonly have a thick, continuous drift cover, consisting mainly of ice-contact and outwash glaciofluvial sediments and lacustrine sediments. This cover ranges up to 30 m or more in thickness over the metavolcanic-metasedimentary rock. The western and eastern portions of the map sheet commonly have a thin, discontinuous drift cover, locally ranging up to several metres in thickness, over the intrusive and sedimentary rock.

One till sheet, varying up to 4 m or more in thickness, was found over the project area. The sedimentary characteristics and contact relationships between the various genetic phases were best observable in backhoe pits or large borrow pits.

The subglacially deposited till facies commonly reflect the local metavolcanic, intrusive or metasedimentary bedrock in colour, texture and dominant clast lithology. In section, a loose to moderately compact melt-out till facies, with sorted and deformed sand bands, commonly grades down into a compact lodgement till facies which in turn overlies bedrock. The lodgement facies commonly has a higher content of fines and higher percentage of local rock types than the melt-out facies. In many locations, melt-out or other till facies overlie bedrock.

The supraglacially deposited till facies reflect local bedrock to a variable extent and have been modified by paraglacial and soil forming processes. Flow till facies were found on or near bedrock knobs and consist of moderately to loosely compacted sandy till with some shaped and striated clasts, sand stringers and crude banding or layering. Ablation till facies were commonly thin, sandy tills with frequent subrounded exotic cobbles and boulders.

Glaciofluvial ice-contact deposits consist of cobbly to bouldery sand and gravel and occur as segmented and beaded eskers, kames, crevasse fill deposits and other stagnant ice features. Small, single ridge eskers lead from higher areas towards the long, fault-controlled valleys. In these major valleys and in the broad, bedrock-controlled topographic lows, large, discontinuous and occasionally compound esker complexes are often present.

Glaciofluvial outwash and deltaic deposits, consisting of pebbly to gravelly sand, flank the esker systems. Kettled outwash occupies large portions of the north-central part of the Sinclair Lake map sheet.

Glaciolacustrine deposits, consisting of rhythmically laminated to massive clay, silt and fine sand, occupy broad bedrock-controlled lows and the margins of the major north-south valleys. Glaciolacustrine deposits up to 15 m in thickness are exposed along the shore of Kapiskong, Sinclair, Marne and Mattagami Lakes.

Aeolian deposits consist of well sorted coarse silt to fine sand and form a thin surficial unit over broad areas. Parabolic and occasional longitudinal sand dunes up to 20 m in height are common in the central and southern portions of the map sheet.

Recent alluvial deposits consist of sand, silt and organic material along the margins of some watercourses in the map areas. Most are of very restricted areal extent and thickness.

Deposits of peat and muck are found in bogs and swamps occupying local topographic depressions and along the meandering streams and rivers. Thin organic deposits occur over extensive areas on lacustrine sand plains in the vicinity of shallow lakes.

APPLIED QUATERNARY GEOLOGY

The project area contains former producing gold and asbestos mines and occurrences and deposits of gold, silver, cobalt, copper, zinc, lead, molybdenum, nickel, iron, and asbestos (Carter 1981; Bright 1970, 1984).

Approximately 10 to 30 percent of the bedrock is exposed in the project area although a much smaller percentage of the metavolcanics are exposed in the Sinclair Lake map sheet.

A reconnaissance till sampling program has been carried out to create a geochemical database and determine if overburden sampling can be effectively used as a mineral exploration technique in the project area. In 1986, 72 samples of till were collected; 98 were collected in 1987.

During traverses, till samples were collected at approximately 1 km intervals where possible. Where weathered till was encountered, samples for geochemical analysis of the -250 mesh (less than 0.063 mm) were collected from the C soil horizon. Where unweathered till was found, a bulk sample (approximately 10 kg) was collected for heavy mineral concentrate (S.G. greater than 3.3) preparation, visible gold grain counts and heavy mineral grain counts. At selected till sample sites, approximately 100 till clasts (2-15 cm b-axis) were collected and the clast rock types were later identified and tabulated for dispersion studies.

Preliminary results of surface till samples collected immediately down-ice of known gold occurrences indicate large numbers of gold grains in the sand size heavy mineral fraction and anomalous gold geochemical values in the silt and clay fraction. Fur-

ther sample processing and analysis of results is in progress.

In the project area, there is no evidence as yet of multiple till sheets from different source areas or till of exotic provenance. Only the upper 4 to 5 metres of the drift cover, however, has been examined and sampled.

Aggregate resources are abundant in the vicinity of the main transportation corridors and settlements. Glaciofluvial and till deposits are mainly used for fill with aeolian and lacustrine sands serving as substitutes.

RELATED RESEARCH

J.T. Aultman is completing a B.Sc. Honours thesis at the University of Western Ontario on the nature of gold dispersal in till down-ice of certain gold occurrences in the Shining Tree area.

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062. Quaternary Geology of the Parry Sound Area

Philip S.G. Kor

Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

Quaternary mapping of the eastern shore of Georgian Bay (*see* location map), initiated in 1986, was continued during the summer of 1987. The 1987 area consists of map sheets Orrville (NTS 31E/5), Magnetawan (NTS 31E/12), Pointe Au Baril Station (NTS 41H/9), Naiscoot River (NTS 41H/10), and Key Harbour (NTS 41H/15). Highways 69, 124, and 518 form the major access corridors through the study area. Numerous secondary and cottage roads east of Highway 69 also provide access. West of Highway 69, boat and aircraft provide the best access due to the general lack of roads.

Previous Quaternary mapping of the area is primarily of a reconnaissance nature (Chapman 1975; Chapman and Putnam 1984), with the engineering and terrain studies of Mollard (1981a, 1981b, 1981c) providing a higher level of detail. Many general and detailed studies of the Lake Huron basin also apply indirectly to the present study area (e.g. Kaszycki 1985). An assessment of the aggregate resources of the Muskoka area (Staff of the Algonquin Region 1983) also includes a portion of the study area. Unpublished reports by Ontario Provincial Parks staff (Haffner and Patten 1971a, 1971b) present detailed information regarding the geology of the two Provincial Parks within the study area.

BEDROCK GEOLOGY

The study area is entirely underlain by strongly foliated, gneissic and migmatitic complexes of the Grenville Province of the Canadian Shield (Hewitt 1967). Minor amounts of paragneiss, amphibolite, quartzite, marble, and basic intrusive rocks also occur (Bright 1986). These rocks are of Precambrian age.

QUATERNARY GEOLOGY

The direction of the last (Late Wisconsinan) glacial advance over the region trends south-southwesterly, with ice-flow indicators, primarily striae, ranging between 172° to 237° azimuth. A slight fanning effect southwesterly into Georgian Bay is noted.

The Parry Sound area was deglaciated about 11 500 B.P. (Before Present), at which time it was submerged in an expanding glacial Lake Algonquin. The stagnating ice front retreated rapidly through the area, forming the north and east shores of the lake. The Main Algonquin lake phase, the highest to form in the basin, was achieved prior to 10 000 B.P. (Eschman and Karrow 1985). At an elevation of about 335 m (1100 feet) above sea level (Sharpe, in preparation), the Main Algonquin phase would have submerged most of the present map area. Changing outlets subsequently lowered the lake rapidly to the Hough phase, exposing much of the map area for the

LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

first time since deglaciation. A long period of transgression to the Lake Nipissing phase once again inundated portions of the study area by about 5500 B.P. Present lake levels were achieved sometime after 3000 B.P. (Eschman and Karrow 1985).

The distribution and thickness of glacial drift in the study area varies greatly. Large tracts of essentially bare bedrock with only minor pockets of sediments dominate west of the CNR railway tracks to the shores of Georgian Bay, and on upland sites throughout the rest of the map area. Surficial deposits, where they occur, typically consist of a thin, discontinuous veneer of stony sand till, and local deposits of ice-contact and lacustrine sediments.

Two till facies have been recognized: a dense, silty sand till, with some fissility and minor clasts; and a loose, stony sand and silt till with abundant clasts. Both facies are thought to have been deposited as basal melt-out due to the occurrence of stratified sandy horizons throughout the tills. Only in a few areas are the tills substantial enough to mask the underlying bedrock topography; notable examples occur in some valley systems perpendicular to ice-flow direction and in local pockets northeast of Magnetawan. Concentrations of erratic boulders are occasionally associated with the till occurrences.

Boulder concentrations throughout the study area suggest the former extent of till deposits, the fines having been removed by wave action during the Lakes Algonquin and Nipissing submergences. Sandy laminae blanketing some till deposits also suggest reworking by lake waters.

Ice-contact deposits are usually scarce, scattered, and thin. Local pockets are typically unsorted to layered, with a highly variable texture, and commonly occur in the lee of bedrock ridges perpendicular to the ice-flow direction. Massive amounts of ice-contact debris are found in the proximal (up-ice) sides of some bedrock valleys perpendicular to the ice-flow direction. Others occur as thin deposits filling bedrock pockets. A subaquatic depositional environment is suggested by crude layering and fluvial structures within the ice-contact debris.

Ice-contact subaquatic outwash fan deposits are located in bedrock depressions throughout the map area. Their deposition was probably confined by ice grounded on local bedrock uplands. The sediments consist of laminated silts, sands, and fine gravels, usually deformed by loading and dewatering, with associated massive sand and diamict flows. These deposits are draped over a fan-shaped core of coarse gravels, cobbles, and sands. They are believed to have been deposited subglacially or near the ice margin into the Main Algonquin lake phase. The fining upward and southward of these deposits reflects the northward retreat of the ice front.

Glaciofluvial deposits occur sporadically in small, linear bedrock depressions and pockets throughout the study area. These deposits consist of crosscut channel-fill sands and gravels with associated ripple-laminated sands and cobble beds, and represent meltwater channels active after glacial lake levels dropped from their high phases. Glaciofluvial gravels and sands commonly form thin channel-fill deposits on pre-existing subaquatic outwash fan deposits, and occasionally on glaciolacustrine deposits.

Glaciolacustrine valley-fill material and fine-grained sediment rhythmites occur scattered throughout the study area, with notable concentrations occuring in the Magnetawan area and south of Orrville. Substantial deposits of sand and fine gravel associated with ice-contact material occupy broad, shallow bedrock valleys in these areas. These deposits represent postglacial depositional environments in an expanding glacial Lake Algonquin. Local deposits are no more than a few metres thick and are usually capped by a thin, laminated, lacustrine sand unit. Rhythmites of grey-green, silt-rich, and red-brown, clay-rich units may represent annual (varved) deposition, as suggested for similar deposits in the Muskoka region (Sharpe, in preparation). The thickness and extent of these deposits generally decreases towards Georgian Bay, reflecting increasing distance from the sediment source during deposition in the Main Algonquin lake phase. Up to 2.5 m of rhythmically laminated silts and clays are located east of Magnetawan, with up to 238 couplets observed.

Near Georgian Bay, shallow bedrock depressions contain thin, massive to laminated silt and sand deposits overlying ice-contact material. One such deposit near Shawanaga was found to contain organic remains, including gastropods, molluscs, and some wood remains. Preliminary examination of similar material found north of Killbear Provincial Park last year indicates that these sediments were probably deposited during the Nipissing transgression about 5000 B.P.

Littoral features of the glacial Great Lakes are restricted to minor beach-facies deposits associated with larger ice-contact complexes. Wave-cut terraces and offshore deposits were not observed in the present map area.

ECONOMIC GEOLOGY

For the most part, the map area is lacking in economic aggregate resources. The chief sources of aggregate in the study area are the ice-contact subaquatic outwash fan deposits in the Orrville area and the glaciolacustrine sand bodies in the Magnetawan area. Numerous small pits are located in lesser deposits of glaciofluvial, ice-contact and glaciolacustrine origin. In addition to being too small, most deposits in the map area are either too fine grained or contain too much over-sized material to be economically important.

RELATED RESEARCH

R. Delorme is studying the subaquatic outwash fan deposits of the map area for a M.Sc. thesis at the University of Waterloo. He is undertaking a detailed analysis of the major borrow pits near Ullswater, Ontario (northeast corner of Lake Joseph map sheet, 31E/4), and will attempt to develop a general depositional model for these sediments in the area east of Georgian Bay.

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063. Quaternary Geology of the Brampton Area

P.F. Karrow

Professor, Department of Earth Sciences, University of Waterloo, Waterloo, Ontario.

INTRODUCTION

Field mapping of the eastern half of the area was completed in 1987. Previous mapping by Watt (1957, 1968) had covered Etobicoke and North York at a scale of 1:31 680 (1 inch to 1/2 mile). The original plan for mapping the Brampton area was to directly incorporate this information. However, as field studies reached the Metropolitan Toronto boundary in 1986 and 1987, the older mapping was found to be incompatible with the current mapping. Surface deposits of lake silt and clay, and areas of bedrock outcrop required greater delineation in the previously mapped areas. Experience with mapping older residential areas near Lake Ontario had proved successful and it was decided to extend the new mapping across the remaining eastern part of the map area as well as to examine any stratigraphic sections available in the valleys of Etobicoke Creek, Humber River, and their tributaries. This additional work was carried out by J. Easton during June, July, and August.

Mapping of the urban areas was difficult, especially in new residential and industrial areas which are commonly regraded through cut and fill operations. Older residential areas were generally less disturbed because construction methods were generally less disruptive. Power line rights-of-way, some parks, and some school grounds were among those sites where undisturbed ground was encountered. Large trees, old enough to predate urbanization, were commonly sought as indicators of relatively undisturbed ground. Air photos from the 1950's were also of some help in urban areas. However, even using these guides, boundaries between map units in urban areas are necessarily less reliable than those in rural areas.

BEDROCK

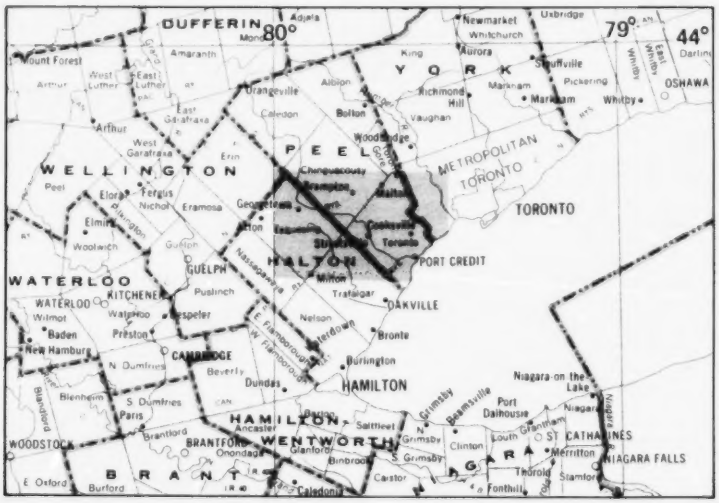
The western part of the area mapped in 1987 is underlain by the red shale of the Ordovician Queenston Formation and the eastern part is underlain by olive to grey shale of the Georgian Bay Formation (Bond *et al.* 1976). Thin drift is common west of the Credit River south from Streetsville, south of Hanlan, along the Lake Iroquois shoreline, and beneath the Iroquois plain.

Affecting both the Queenston and Georgian Bay Formations are "pop-ups", recognizable in stream bank and quarry exposures as small anticlinal folds one to two metres high, or as ground surface linears in areas of shallow drift. Most of the latter could only be seen on 1950's air photos, urbanization having subsequently destroyed or concealed them. Since these features are evident at the ground surface, they are believed to have formed in postglacial time.

QUATERNARY DEPOSITS

North of the Lake Iroquois bluff, the principal surface material is the gritty, silty Halton Till; this material also forms a subdued undulating ridge known as the Trafalgar Moraine extending from south of Streetsville to the Toronto Airport, much of the latter being situated on its crest. Scattered exposures reveal that fine sand underlies the Halton Till over substantial areas. In one excavation at Erin Mills and in one stream bank west of Weston, fine plant detritus was encountered in these sands. Little evidence of a pre-Halton Till was encountered.

The glacial Lake Iroquois shoreline is represented by a low bluff extending from Clarkson to Weston. West of Cooksville the bluff is eroded in bedrock. Small areas of sand and clay, mainly along valley flanks north of the Iroquois bluff, represent deltaic and fluvial terrace deposits of pre-Iroquois age asso-



LOCATION MAP Scale . 1 : 1 548 000 or 1 inch to 25 miles

ciated with the declining levels of Lake Peel. At valley mouth re-entrants, along the Iroquois shoreline gravel baymouth, bars occur as at Erindale, Cooksville, and Burnhamthorpe.

The Lake Iroquois plain, south of the Iroquois shoreline, is generally underlain by shallow water, fine sands deposited in Lake Iroquois. Occurrences of till are uncommon and bedrock occurs at the surface near Clarkson and Cooksville. Small areas of deeper water clay deposited in Lake Iroquois occur near Lake Ontario east of Port Credit.

Sections along the upper Humber River reveal up to 6 m of Lake Peel silt and clay filling depressions in the Halton Till surface; these sediments display fining upward proximal to distal sequences. Sections in lower valley locations nearer Lake Ontario reveal Lake Iroquois sediments varying from nearshore gravel and sand, to estuarine silts and deeper water, varved clays.

ECONOMIC GEOLOGY

Bedrock quarries continue to provide shale for the manufacture of brick at Streetsville (Queenston Formation) and Cooksville (Georgian Bay Formation). Large areas of shallow drift are rapidly being urbanized and the underlying bedrock is effectively removed from consideration for future exploitation.

Gravel extraction, formerly active in the Lake Iroquois beach deposits, has ceased and most areas are already covered or are being covered, with houses. Peat was formerly extracted from a deposit southeast of Britannia but this activity has dwindled to individuals obtaining supplies for gardening; the deposit is now largely depleted and built over.

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064. Synoptic Studies of the Quaternary Geology, Metropolitan Toronto Area

R.I. Kelly

Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

A project to compile and interpret the geology and engineering properties of the Quaternary strata of the Metropolitan Toronto area was started by the Ontario Geological Survey during the late 1970's (Sharpe 1980). The emphasis of this ongoing project is to collect and process subsurface data which becomes available through borehole investigations, temporary excavations, and natural exposures. The collected information is added to a central databank which may then be accessed for future geological and geotechnical studies.

PRESENT WORK

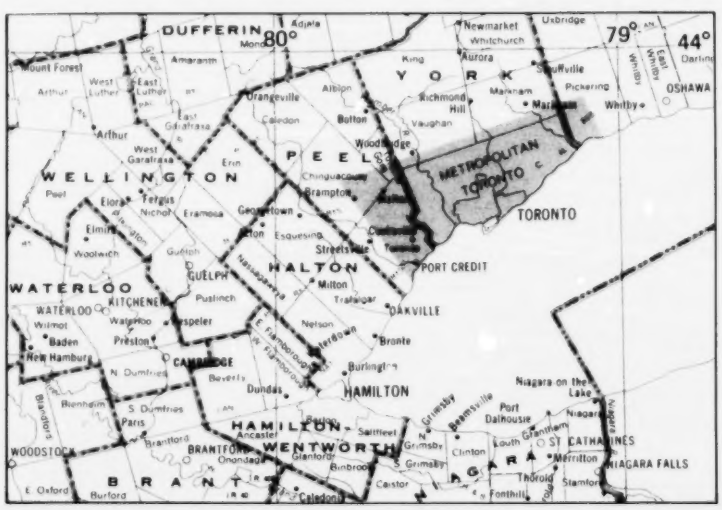
The present work has two major aims: to add additional Quaternary information to the existing databank; and secondly, to investigate the nature of Quaternary depositional environments through detailed sedimentological examination of the glacial and non-glacial strata.

During the past summer, six weeks were spent investigating natural exposures in the valleys of the Credit, Humber and Don rivers as well as West Duffin and Little Rouge creeks. For each section investigated, a series of smaller subsections were exposed, logged in detail, photographed and where deemed necessary, sampled. By employing this procedure, sections could be documented from the bottom to the top of the exposure.

OBSERVATIONS

Some initial observations can be outlined as follows:

1. Sections in the Humber River Valley near the village of Kleinburg and north of the village of Woodbridge generally show a continuous upward fining sequence of sediments. This sequence includes, from bottom to top, fluvial gravels and/or sands, rhythmically-bedded lacustrine silts and clays, silty to sandy silt diamicts interbedded with fine-grained rhythmites and finally into silty to sandy silt and massive to sometimes faintly stratified till. The lower gravels and sands are crossbedded with paleocurrent measurements indicating flow to the north or northwest. The rhythmites often contain numerous whitish silt pellets and small lonestones. Where rhythmites are interbedded with diamicts the thicker diamicts (up to 50 cm thick) appear to be of flow origin. Thinner (1 to 3 cm thick) diamict layers were likely deposited by bottom density currents. The till which caps many of the examined sections is for the most part massive with few pebbles. Fabric analysis of pebbles from this till indicates ice flow toward the northwest. This till is probably the Halton Till (White 1975).
2. Exposures examined on the west branch of the Don River between Highways 7 and 401 generally show a complex interbedding of fine-grained rhythmites, sands and silt or clay-rich diamicts. Often the sequences are capped by a thick (up to 10 m), massive, silty to sandy till which erosively overlies the underlying sediments. The interbedded complex contains fine-textured diamict units, up to 2 m thick, composed of thin, massive, silty sand layers with many silt pellets, faintly laminated silty sand layers and stratified, coarser-textured diamict layers. Small pebbles, generally limestone are found throughout the units. Interbedded with the diamict units are rippled sand sets and rhythmically-bedded



LOCATION MAP Scale : 1 : 1 548 000 or 1 inch to 25 miles

silts and clays. Paleocurrent directions obtained from the sands are for the most part toward the north, varying from northwest to northeast. Stratigraphically, the uppermost till is probably the Halton Till (Sharpe 1980). The underlying complex of diamicts, sands, and rhythmites is tentatively considered to be related to the Seminary, Meadowcliffe, and Thorncliffe complex of diamicts and stratified sediments previously described by other workers (Karrow 1967, 1969; Eyles and Eyles 1983).

3. Sections along Little Rouge Creek between Finch Avenue to the north and Twyn Rivers Drive to the south were examined in an attempt to integrate the present study with the sites described by Karrow (1967). These sections are most often composed of interbedded diamicts and glaciolacustrine sediments. It would appear that this complex is stratigraphically related to the Sunnybrook Drift. The lower part of the sequences consists of interbedded diamicts and rhythmically-bedded silts and very fine sands. Upward, the sequence changes to essentially massive to sometimes faintly stratified till. Very prominent boulder pavements have been identified in the upper part of the sequence. Clast orientation and striae indications from the boulder pavements indicates ice flow from the northeast.

Field investigations were carried out with the assistance of Kathy O'Keefe. John Easton and Eric Wright examined sections along the Credit River and lower reaches of the Humber River. The cooperation of the Metropolitan Toronto Regional Conservation Authority and Metropolitan Toronto Parks for allowing this work to be conducted on their properties is also gratefully acknowledged.

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065. Aggregate Resources Inventory of the Echo Bay—Bruce Mines Area and St. Joseph Island

Mary Gauvreau[1], Robert Gorman[2], and Steve Szoke[3]

[1]Geological Assistant, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

[2]Resource Geologist, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

[3]Supervisor, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

During the autumn of 1986 aggregate assessments were undertaken in 15 geographic townships in the Echo Bay-Bruce Mines Area and on St. Joseph Island. The townships assessed on the mainland included: Macdonald, Meredith, Aberdeen Additional, Aberdeen, Laird, Tarbutt, Tarbutt Additional, Johnson, Plummer, and Plummer Additional. Parts of Rose and Lefroy Townships were also investigated. All of St. Joseph Island was assessed, including St. Joseph, Hilton, and Jocelyn Townships. Population centres within the report area included the town of Bruce Mines and the village of Hilton Beach, as well as other communities such as Echo Bay, Desbarats, and Richards Landing.

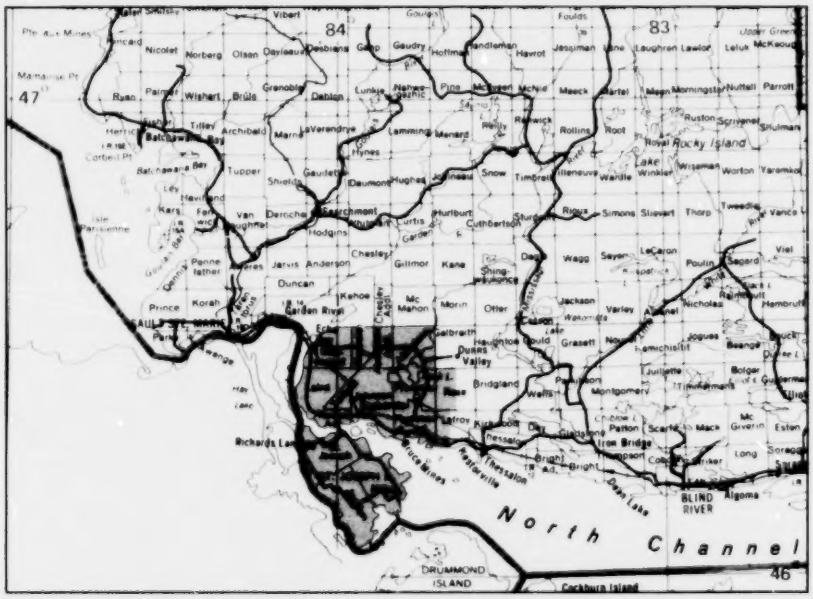
The purpose of this investigation was to delineate and determine the quality and quantity of aggregate within the area for both road-building and general construction uses. This information was required for the evaluation of development potential and for land use decisions.

During the field investigation all potential aggregate deposits were examined in detail. Observations made at pit sites included the estimation of the face height, of the percentage of gravel and sand, and of the amount of objectionable materials present. Soil probing, hand augering, and geophysical techniques were used to assess subsurface materials in areas of limited exposure. A number of test holes were excavated using a backhoe, and aggregate samples were collected for quality testing.

BEDROCK

Bedrock of Precambrian age is exposed throughout much of the mainland study area and on the northern shore of St. Joseph Island (Giblin and Leahy 1979). These rocks consist predominantly of a complex array of metasedimentary rocks of the Huronian Supergroup and the intrusive Nipissing diabase. The Precambrian bedrock typically demonstrates rock knob or rock ridge topography over much of the mainland (McQuay 1980; Van DINE 1980a, 1980b).

Bedrock of Paleozoic age underlies small portions of the mainland study area and most of St. Joseph Island. A narrow band of sandstone of the Munising Formation occurs south of the Precambrian rocks along the north shore of the island. On the mainland, sandstone of the Jacobsville Formation underlies parts of Macdonald and Laird Townships. Most of St. Joseph Island is underlain by Paleozoic



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

shale and carbonates including undifferentiated Middle and Upper Ordovician carbonates, the Collingwood Member of the Lindsay Formation, the Blue Mountain Formation and the Georgian Bay Formation (Russell 1985). Outcrop of Paleozoic rocks on St. Joseph Island is restricted to the northern rim of the island. Elsewhere, the bedrock is thickly covered by glacial deposits.

SURFICIAL GEOLOGY

The oldest surficial sediments found in the report area are silts and sands which are thought to be of glaciofluvial outwash or deltaic origin (Karrow, in preparation). These sediments appear to form the base of a large hill composed entirely of drift. This hill, located in the centre of St. Joseph Island, is known locally as "The Mountain" and will be referred to as such in this report.

Till is the oldest widespread surficial sediment in the report area. It was deposited as a thin veneer over bedrock and previously existing sediments during the last glacial advance (Boissonneau 1968; Karrow, in preparation). On St. Joseph Island till is also found in the form of drumlins and moraine ridges, especially in the northwestern portion of the island. Till is generally not well suited for aggregate use because it often contains excess fines and abundant oversize clasts. In some localities till may be acceptable for use as fill.

Deposits of ice-contact stratified drift were laid down in close proximity to the ice front as it melted back to the north. These deposits are widespread in the Echo Bay-Bruce Mines Area. On St. Joseph Island ice-contact deposits are less extensive and are restricted for the most part to the northwestern part of the island (Karrow, in preparation).

As the ice front continued to melt back, meltwaters flowing into a proglacial lake in the Lake Huron basin flooded much of the study area. Only the high rock knobs and ridges on the mainland and The Mountain on St. Joseph Island were not submerged. The glacial lake waters reworked the previously existing sediments and deposited medium to fine sand, silt, and clay in areas of lower elevation throughout the report area. In the shallow water, high-energy lacustrine environment, till and ice-contact deposits were reworked into lacustrine beaches. On St. Joseph Island, wind action redeposited lacustrine sand as dunes.

AGGREGATE DISTRIBUTION AND QUALITY

Ice-contact stratified drift deposits are the major sources of aggregate in the Echo Bay-Bruce Mines Area. A number of deposits occur as small patches of sand and gravel flanking the south side of rock knobs. These deposits generally contain only limited resources of aggregate. More extensive ice-contact deposits occur east of Echo Bay, south of MacLennan, and west of Eleanor Lake. Many of these ice-contact deposits have been modified by wave action. An esker south of Richards Landing on St. Joseph Island, and several small kame deposits north and west of the esker, are potential sources of aggregate. Generally, the ice-contact deposits in the study area are considered to be well suited for the extraction of pit-run aggregate and possibly crushable gravel.

Lacustrine beach deposits are important potential sources of aggregate on St. Joseph Island. The largest beach deposit encircles The Mountain and contains significant amounts of crushable gravel. The material contained in a large beach deposit located to the east of The Mountain, and in a number of smaller beach and bar deposits, is variable and is suitable for a number of aggregate uses. Small beach deposits on the mainland are sources of pit-run aggregate.

The aggregate in the study area appears to be hard and durable and suitable for most road-building and general construction applications. Use of the gravel in portland cement concrete may be limited by the presence of argillite, greywacke and sandstone clasts of the Huronian Supergroup. These clasts are potentially alkali-reactive (Rogers 1985) and testing of the aggregate is strongly recommended prior to use in concrete products.

With the exception of Tarbutt and Meredith Townships, the townships within the report area appear to contain substantial aggregate resources that should be sufficient to meet local requirements for a considerable period of time.

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066. Aggregate Resources Inventory of the Bruce Peninsula

Mary Gauvreau[1] and Steve Szoke[2]

[1]Geological Assistant, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

[2]Supervisor, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Field work was conducted on the Bruce Peninsula, in northern Bruce County, during the 1987 field season as part of the Aggregate Resources Inventory Program. The townships assessed included St. Edmunds, Lindsay, Eastnor and Albemarle. Further investigation of Amabel Township was also undertaken to supplement previous field work done in the township. The results of the field investigations will be published in Aggregate Resources Inventory Papers or released in Open File Reports, as applicable.

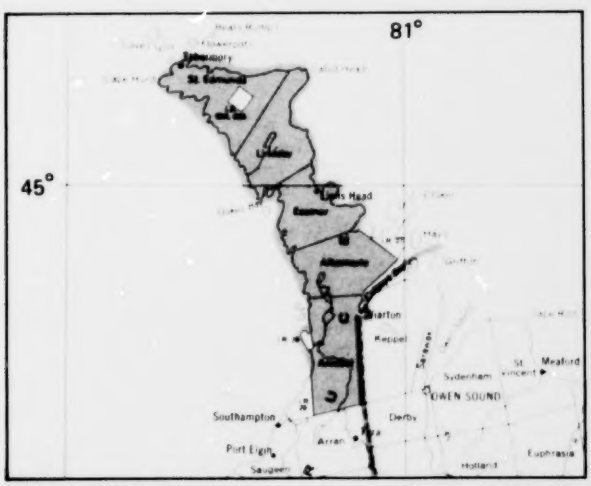
Field investigations consisted of the following activities: examination of potential aggregate deposits, existing pits and quarries, and natural and man-made exposures, as well as auger drilling. Active and abandoned pits were investigated and at each site several observations were made, including the estimation of the face height, the percentage of gravel and sand, and the presence of deleterious materials such as chert, shale, clay, silt, and oversize boulders. The intended uses of the granular material and the presence of stockpiles, water-filled ponds, crushing plant, and rehabilitation work were also noted. Estimates were made of the amount of material previously extracted from these pits to enable resource tonnage evaluations to be determined. Active and abandoned quarries were also visited. At these sites, the height of the quarry face was noted, as well as the bedrock geology, and the presence of deleterious materials.

The purpose of the field investigations was to confirm and supplement the information gathered from various sources such as existing geological reports and maps, data from the files of the Ontario Ministry of Transportation, and water well data from the Ontario Ministry of the Environment. In areas where pre-existing data were unavailable or insufficient, representative channel face samples were taken from exposed faces. These samples have been sent to the Ontario Ministry of Transportation to be analyzed for grain size distribution, soundness, absorption, and lithology (petrographic number or P.N.).

GEOLOGY AND AGGREGATE POTENTIAL

The dominant aggregate-bearing deposits in the Bruce Peninsula project area are glaciolacustrine beach deposits formed by glacial lakes Algonquin and Nipissing. Ice-contact deposits, eskers, and outwash deposits found in the southern part of the project area are also sources of sand and gravel.

The Georgian Bay ice lobe stagnated briefly in the project area, allowing ice-contact stratified drift and eskers to be deposited in southeastern Amabel Township (Sharpe and Jamieson 1982). These deposits are generally thin, and contain poorly sorted fine gravel in a medium- to coarse-sand matrix. Eastern Albemarle Township contains unusual outwash material which was primarily derived from the dolostone of the Amabel Formation which outcrops along the Niagara Escarpment. The material appears to have been transported short distances prior to deposition. The outwash generally consists of fine to coarse subangular to subrounded gravel in a medium- to coarse-sand matrix. An outwash deposit west of Sydney Bay contains very coarse, blocky material with a large amount of oversize clasts.



LOCATION MAP

Scale: 1:1 584 000
or 1 inch to 25 miles

Beach deposits derived from previously existing till and other surficial sediments by the waters of glacial lakes Algonquin and Nipissing are numerous in Amabel Township. In the other townships in the project area beach deposits are sparse and are generally small, thin, and contain only a limited amount of poorly sorted, subangular material. Two large, thick beach deposits, one located south of Tobermory and the other located southwest of Lion's Head, have been sources of good quality aggregate suitable for a wide range of road-building and construction needs.

Fine to medium sand suitable for use as fill occurs in an extensive aeolian deposit that parallels the Lake Huron shoreline in Amabel and Albemarle Townships. Smaller aeolian deposits occur north of this deposit along the western side of the Bruce Peninsula.

In general, sand and gravel resources in the Bruce Peninsula study area are considered to be limited, particularly in Lindsay Township. Amabel Township is an exception as it appears to contain locally significant deposits of sand and gravel.

Large parts of the study area consist of bedrock outcrop or bedrock covered by relatively thin drift. The bedrock consists of a succession of shales and dolostones of Upper Ordovician to Middle Silurian age. The Queenston, Manitoulin, Cabot Head, and Fossil Hill Formations outcrop along the Georgian Bay shoreline and in the base and face of the Niagara Escarpment. The dolostone of the Amabel Formation forms the resistant caprock of the Niagara Escarpment and outcrops in the face of the escarpment and over much of the eastern part of the Bruce Peninsula. The dolostones of the Guelph Formation outcrop on the western half of the Bruce Peninsula (Liberty and Bolton 1971).

In northern Amabel Township, the Eramosa Member of the Amabel Formation is being quarried to produce coursing stone, flagstone, sills, steps and other ornamental stone. The Eramosa Member is not suitable for aggregate use because it contains thin layers and shaly partings. At a quarry near Hope Bay in Albemarle Township, the Wiarton/Colpoy Bay Member of the Amabel Formation is being quarried for building stone. Non-reefal areas of the Amabel Formation are of high quality and are suitable for use in crushed stone, concrete aggregate, building stone, and as raw material for lime manufacture.

Areas of the Guelph Formation covered by thin drift also hold potential for future quarrying. The Guelph Formation has been used elsewhere primarily for the production of high purity dolomitic lime. The suitability of the Guelph Formation found in this part of Ontario for aggregate has not yet been established. Several samples of the Guelph Formation were taken during field investigation to be tested for aggregate suitability by the Ontario Ministry of Transportation.

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067. Aggregate Resources Inventory of the Parry Sound–French River Area

G.R. Jones[1], C.J. Cameron[2], and Steve Szoke[3]

[1]Resource Geologist, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

[2]Geological Assistant, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

[3]Supervisor, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

During the 1987 field season, aggregate assessments were undertaken in 15 geographic townships in the District of Parry Sound. The townships flank King's Highway 69 and extend along the eastern shore of Georgian Bay from the vicinity of the town of Parry Sound to the French River. The townships assessed include Henvey, Mowat, Blair, Wallbridge, Brown, Harrison, Shawanaga, Carling, Ferguson, McDougall, Cowper, Foley, Christie, Conger and Humphrey. Population centres in the report area include the town of Parry Sound, the village of Rosseau, and the communities of Britt, Byng Inlet, Pointe au Baril Station, Nobel, Orrville, and Humphrey.

The purpose of the investigation was to delineate and determine the quality and quantity of aggregate within the area for both road-building and general construction uses. This information is required for the evaluation of development potential and land use decisions.

During the field investigation, all potential aggregate deposits, and both natural and man-made exposures, were examined in detail. Observations made at pit sites included the estimation of the face height, the percentage of gravel and sand, and the amount of objectionable materials present. Soil probing, hand augering, and geophysical techniques were used to assess subsurface materials in areas of limited exposure. A number of test holes were excavated using a backhoe, and aggregate samples were collected for quality testing.

Quaternary geology mapping by Kor (1986; this volume, article 062) provided the framework for the detailed aggregate study. Geological studies by Chapman and Putnam (1984) at a reconnaissance level and engineering and terrain studies by Mollard (1980a, 1980b, 1980c) and Gartner (1980) also cover the area.

LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

BEDROCK

The bedrock in the project area is part of the Grenville Province of the Canadian Shield. It consists largely of strongly foliated gneissic and migmatitic rock with minor bodies of quartzite, amphibolite, marble and basic intrusive rock (Hewitt 1967). In general, the bedrock is hard and resistant to weathering, and is considered to be a potential source of aggregate. A number of quarries have been developed within gneissic rocks in the area, mainly to provide crushed stone for highway construction. Several quarries are adjacent to King's Highway 69. Most of the quarries were inactive during field investigation with the exception of two sources in the vicinity of Parry Sound. The quarries have generally been developed in response to a severe shortage of glacial deposits containing crushable gravel in the study area.

SURFICIAL GEOLOGY

A discontinuous cover of till was deposited sporadically within the project area by glacial ice which advanced in a southwesterly direction (Kor 1986). This sandy till generally exists as a thin veneer over bedrock. Till is usually not well suited for aggregate use because it often contains excess fines and abundant oversize clasts. However, till may be a suitable source of fill in some localities.

Ice-contact features are scattered throughout the project area. They are often located on the southern flank of bedrock knobs and ridges, and are limited in areal extent. The deposits consist of variably bedded sand and gravel which was deposited as the glacial ice melted back from the area.

During deglaciation the land surface was submerged beneath glacial lake waters. Subaqueous fans were deposited by meltwaters entering these lakes directly from the glacial ice. Most of these fans are situated within south- to southwest-trending bedrock depressions in the area. On the floors of the glacial lakes, sand, silt and clay were deposited. These lake-bottom sediments occupy low-lying areas throughout the report area. Outwash and deltaic sands were deposited in localized areas as water levels lowered in the lakes.

AGGREGATE DISTRIBUTION AND QUALITY

Subaqueous fan deposits are the major sources of aggregate in the study area. Although the fans occur locally throughout the project area, the major fan deposits are located in McDougall, Foley, Christie and Humphrey Townships. Typically, the fans consist of fine to coarse sand and may contain minor amounts of fine gravel. The aggregate in these features tends to become finer near the surface and the fans are often capped by 1 m of silt and clay. The silt and clay should be stripped off prior to aggregate extraction to avoid contamination of the underlying material. In some areas the fan deposits may contain gravel which would be suitable for crushing if selective extraction and sand control measures were employed. During field investigations gravel was often found to be concentrated in the lower levels of pits and was often below the water table.

Although the ice-contact features in the report area are usually small, many of the deposits are important local sources of aggregate. Material exposed in these deposits varies from fine sand to coarse gravel suitable for crushing. Ice-contact material has been the primary source of aggregate for the construction of resource access roads in the northern part of the project area.

The sand and gravel deposits in the study area often show wide variations with respect to aggregate quality. Many of the deposits contain clean sandy aggregate well suited for the production of a variety of sand products. Several of the sand deposits, however, contain enough fines to limit high specification aggregate uses. Silt and clay seams as well as silty, fine sand units are common in some pits. The gravel in the area appears suitable for most usual aggregate applications where it is present in sufficient quantities. It may contain highly weathered and friable rock which can restrict its use in high specification products, particularly in concrete. In the northern part of the project area the gravel contains greywacke and sandstone clasts of the Huronian Supergroup which are potentially alkali-reactive in concrete mixes (Rogers 1985).

In general, the northern part of the report area contains only limited amounts of aggregate. Existing deposits in this area are usually small isolated bodies suitable for local use. In the northern townships large tracts of land contain little or no aggregate resources. Consequently, aggregate may have to be transported lengthy distances to supply construction needs in certain areas. Aggregate is dredged from the waters of Georgian Bay to supply cottage construction needs along the northeastern shore of the bay.

The southern part of the project area contains relatively more aggregate resources. These resources primarily consist of sandy aggregate suitable for such uses as road sub-base, septic beds and fill. Supplies of crushable gravel are lacking throughout the project area. Bedrock-derived aggregate from local quarries as well as sources outside the project area is the primary source of crushed stone.

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068. Paleozoic Geology of the Northern Bruce Peninsula

D.K. Armstrong

Geologist, Paleozoic/Mesozoic Geology Subsection, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

During the summer of 1987, mapping of the Paleozoic strata of the northern Bruce Peninsula of southern Ontario was undertaken as the initial phase of a multi-year mapping program, designed to cover the entire Bruce Peninsula. Although stratigraphic nomenclature has changed somewhat over time, previous Paleozoic geology maps of the Bruce Peninsula (Williams 1919; Caley 1945; Liberty 1966; Liberty and Bolton 1971) are generally consistent in their delineation of most of the formational contacts. Significant exceptions are the variable distributions among these maps of the two uppermost formations exposed on the Peninsula, the Amabel and Guelph Formations. In addition, the areal distributions of the members within the Amabel Formation have never been delineated. This is of economic significance as two of these members, the Eramosa and the Wiarton/Colpoy Bay, are important sources of building stone on the Bruce Peninsula (Armstrong 1986).

The objectives of the Bruce Peninsula mapping program are to resolve previous stratigraphic inconsistencies in light of more recent revisions in stratigraphic nomenclature, and to produce a series of maps which might better aid in potential resource delineation and evaluation.

LOCATION

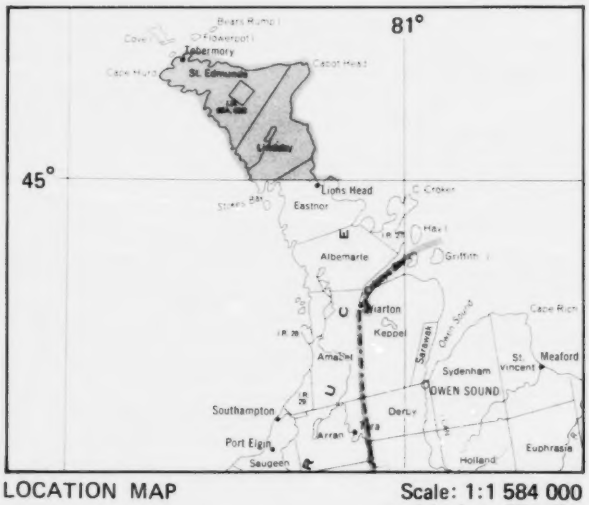
The 1987 mapping area (*see* Location Map) consists of the Bruce Peninsula north of Latitude 45°00'N, and is covered by 1:50 000 NTS map sheets of Dyer's Bay (41H/3), Dorcas Bay (41H/4), and the southernmost (i.e. mainland only) portion of the Flowerpot Island sheet (41H/5). The map area can be accessed by King's Highway 6, via Owen Sound and Wiarton. Other public and private roads provide good access in much of the map area. Access to some of the more remote regions in the map area are afforded by the Bruce Trail, other hiking and hunting trails, and old lumber roads.

GENERAL GEOLOGY

Previous contributions to our understanding of the Paleozoic geology of the Bruce Peninsula consist of three generations of maps (referenced above), and reports dealing with aspects of the stratigraphy, paleontology, and depositional history of the Silurian strata (Williams 1919; Bolton 1953; Bolton 1957; Sanford 1969; Liberty and Bolton 1971). The following section will review the stratigraphy encountered in this summer's mapping, highlighting particularly good or new exposures and some of the difficulties encountered within the confines and ambiguities of the established nomenclature.

Strata from Upper Ordovician through to Middle Silurian age are exposed in the northern Bruce Peninsula area. The outcropping units are listed in the stratigraphic column in Figure 068.1. Outcrops of the Upper Ordovician to lower Middle Silurian units are restricted to the eastern and northeastern shores of the Peninsula along the base of the Niagara Escarpment. Middle Silurian dolostones form the steep cliffs of the Escarpment and are exposed in low glacially fluted hills or bedding plane outcrops over the remainder of the Peninsula.

The lowest strata exposed on the northern Bruce Peninsula are red shales of the Upper Ordovician Queenston Formation. These are poorly exposed at lake level, below, and just south of the Cabot Head lighthouse (NTS 41H/3, UTM 477100mE,



LOCATION MAP

Scale: 1:1 584 000
or 1 inch to 25 miles

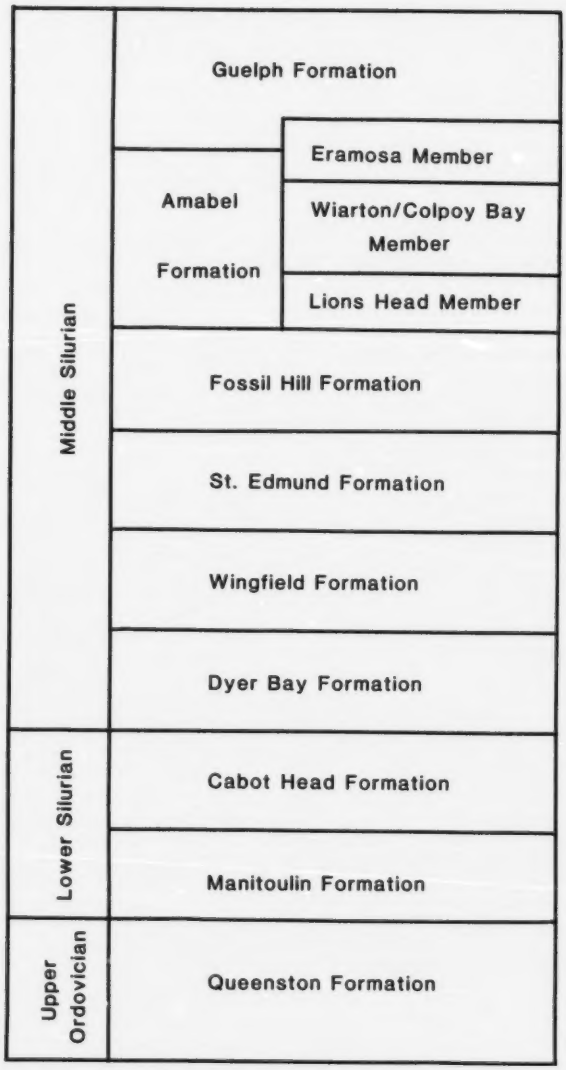


Figure 068.1. *Stratigraphic nomenclature of exposed Paleozoic strata on the northern Bruce Peninsula (modified after Bolton 1957; Sanford 1969; and Liberty and Bolton 1971).*

5010000mN), in the northeastern corner of the Bruce Peninsula. The Queenston Formation is sharply overlain by the thin-bedded, grey to blue-grey dolomitic limestones and dolostones of the Lower Silurian Manitoulin Formation. This formation is exposed only in cliffs (<15 m high) near lake level in the vicinity of Cabot Head.

The Manitoulin Formation is overlain by a sequence of interbedded shales and dolostones which range in age from Lower Silurian through to Middle Silurian. The four units comprising this sequence are, (in ascending order), the Cabot Head, Dyer Bay, Wingfield, and St. Edmund Formations. Although these units have been included as members within the Cabot Head Formation by some previous workers (Liberty and Bolton 1971), the nomenclature used in this report is that of earlier workers (Bolton 1957; Sanford 1969) and that used in more recent mapping of Manitoulin and Cockburn Islands (Johnson and Telford 1985; Wolf 1986) northwest of the Bruce Peninsula.

The Cabot Head, Dyer Bay, Wingfield, and St. Edmund Formations are well exposed at Rocky Bay (NTS 41H/3, UTM 472000mE, 5009500mN), approximately 4.5 km west of Cabot Head, on the northern shore of the Bruce Peninsula. They are less well exposed south of Cabot Head in Boulder Bluff (NTS 41H/3, UTM 477400mE, 5008350mN), and further south along the eastern shore of the Peninsula, near Dyer Bay and Cape Chin. Because of the shaly nature of the Cabot Head and the Wingfield Formations, this sequence is generally talus covered and forms steep wooded slopes beneath the main escarpment.

In the northern Bruce Peninsula area, the Cabot Head Formation is predominantly a red shale with subordinate grey-green shale beds at the top and as thin interbeds. The Wingfield Formation is a grey-green shale with thin dolostone interbeds and the Dyer Bay and St. Edmund Formations are thin-bedded, well-jointed dolostones. The Dyer Bay Formation exhibits a variety of sedimentary structures, abundant fossil forms (bryozoans, corals, brachiopods, etc.), and a varied and abundant trace fossil assemblage. Good accessible exposures of the Dyer Bay Formation can be found along the shores of Dyer Bay and Cape Chin.

The Middle Silurian Fossil Hill Formation overlies the St. Edmund Formation in the northern Bruce Peninsula area. This unit is a distinctive thin-bedded, fossiliferous (pentamerid brachiopods, corals, and stromatoporoids) dolostone which commonly forms small (up to 7 m high) cliffs below the main Niagara Escarpment face. A complete interval of the Fossil Hill Formation is exposed in Boulder Bluff south of Cabot Head. Other good exposures exist at Rocky Bay, Cape Chin, and in spectacular bedding plane outcrops in the extreme southeastern corner of the map area along the shores of Ismuth and Whippoorwill Bays, north of Lions Head.

Thick- to massive-bedded dolostones of the Middle Silurian Amabel Formation form the main steep cliffs of the Niagara Escarpment and outcrop in low rolling hills west of the Escarpment face. Previous workers, such as Bolton (1957), have subdivided the Amabel Formation into four members, whereas others, (e.g. Liberty and Bolton 1971) have combined Bolton's two middle members, resulting in a threefold subdivision: (in ascending order) the Lions Head, Wiarton/Colpoy Bay, and Eramosa Members. Mapping of the Amabel Formation within the structure of either of the above nomenclatures proved difficult in the northern Bruce Peninsula area, suggesting that these subdivisions are not laterally continuous.

Aside from the distinctive Eramosa Member lithotypes, as described by Armstrong and Meadows (in press), which were identified locally in the map area, the Amabel Formation was found to consist of three general lithotypes in the northern Bruce Peninsula area. The first lithotype consists of very thick- to massive-bedded, fine- to coarse-crystalline, light

grey-white to light tan, variably mottled (generally blue-grey) dolostone, with an apparent (obscured due to dolomitization) fossil content ranging from less than 2 percent up to 10 percent of the volume. Fossils are primarily echinoderms (ossicles and columnals), with sparse corals, stromatoporoids, and brachiopods. The second Amabel Formation lithotype is similar to the first except that it is medium- to coarse-crystalline, light tan-grey to creamy tan in colour (also variably mottled), generally more irregularly bedded, and more fossiliferrous (locally echinoderm-rich or with abundant framebuilders). This lithotype appears biostromal and locally is probably biohermal. The third Amabel lithotype is a thin- to thick-bedded, fine- to medium-crystalline, light grey-tan to creamy tan, sparsely fossiliferous dolostone, with platey to blocky parting, local micro-stylolite swarms, local chert nodules or lenses (sometimes replacing fossils), and variably developed purple-red to brown mottling. Refinement of these lithologic subdivisions is being attempted through petrographic analysis. These Amabel lithotypes exhibit no distinct stratigraphic distribution on the northern Bruce Peninsula, however, subsequent mapping to the south may better elucidate the internal stratigraphy of this formation.

The Guelph Formation outcrops in glacially fluted hills and bedding planes in the centre of the Peninsula, in large rugged bedding plane surfaces on the western shore, and in cliffs on the northern shore. This formation consists predominantly of thin- to thick-bedded, fine- to medium-crystalline, light grey-tan to light brown dolostone. It has a variable fossil content which is indicated by fine, apparently moldic, porosity. This lithotype is generally planar-bedded and exhibits a coarse ribbing on weathered surfaces due to the interbedded nature of more recessive fossil-rich (up to 20 percent) beds, and more resistant fossil-poor beds. Fossil types in the Guelph Formation include gastropods, brachiopods, pelecypods, stromatoporoids, corals, and echinoderms. Locally fossil content is sufficient to suggest biostromal development. In some areas, abundance of frame-building organisms, irregular thick to very thick bedding, and adjacent sub-horizontal (on-lapping?) beds indicate biohermal development. Biohermal zones are locally evident along the northwestern shore of the Bruce Peninsula, especially in the vicinity of Cyprus Lake Provincial Park, and at the southern end of the map area in the Forty Hills area.

The lower contact of the Guelph Formation with the Amabel Formation is not always clear in the field. Presence or absence of mottles, bedding thickness, crystal size, colour, and to some extent topography were used to determine contact placement. The Guelph/Amabel contact sometimes appears gradational and commonly only one or two of the above characteristics may vary across the contact. Locally mottled (i.e. an Amabel Formation characteristic) cores of apparent Guelph Formation bioherms and other topographic inconsistancies suggest that either the upper Amabel and lower Guelph strata are coeval lateral equivalents or that there was considerable topography on the upper surface of the Amabel Formation.

The laminated, bituminous, thin-bedded dolostones of the Eramosa Member have been assigned to the Amabel Formation (Bolton 1957; Liberty and Bolton 1971). Where present, the Eramosa Member is generally found in the vicinity of the Guelph/Amabel contact. Lithologically, it has affinities to the Guelph Formation (i.e. colour, crystal size, bedding thickness) and strata with Eramosa-like characteristics occur at Driftwood Cove (NTS 41H/4, UTM 454300mE, 5009550mN) on the northern shore of the Peninsula (approximately 7 km east of Tobermory), apparently well up into the Guelph Formation interval. A recent study of the Eramosa Member in the south-central area of the Bruce Peninsula (Armstrong 1986; Armstrong and Meadows in press) suggests that the Eramosa is more closely related to the Guelph Formation than the Amabel Formation. Sanford (1969), in fact, places the Eramosa Member within the Guelph Formation. This uncertainty in the stratigraphic placement of the Eramosa Member strata is indicated in the stratigraphic column in Figure 068.1. The interrelationships among the Eramosa Member and the Guelph and Amabel Formations will be further investigated during subsequent mapping seasons on the Bruce Peninsula.

ECONOMIC GEOLOGY

The Amabel and Guelph Formations have been quarried for lime, building stone, and aggregate on the Bruce Peninsula since the turn of the century (Parks 1912; Goudge 1938; Hewitt 1960, 1964; Hewitt and Vos 1972). Other units on the Peninsula (e.g. the Manitoulin Formation) have also been quarried intermittently for aggregate and building stone. Currently, the Eramosa and Wiarton/Colpoy Bay Members of the Amabel Formation are quarried for building stone in the southern portion of the Bruce Peninsula (Armstrong 1986; Armstrong and Meadows in press). In addition, the Wiarton/Colpoy Bay Member is quarried for aggregate at the E.C. King Limited Quarry east of Owen Sound. Although the Guelph Formation is quarried in southern Ontario for lime and construction aggregate (Hewitt and Vos 1972), it remains an untested potential resource on the Bruce Peninsula.

Because previous mapping on the Bruce Peninsula (referenced above) only identified formational contacts, one of the objectives of this study is to explore for and delineate strata with significant resource potential. Outcrops of one such unit, the Eramosa Member, were found in the Marley Lake (NTS 41H/3, UTM 466000mE, 5004000mN) and George Lake (NTS 41H/3, UTM 464700mE, 5004700mN) areas (in the north-central area of the map area), and southeast of Miller Lake (NTS 41H/3, UTM 471900mE, 4994700mN). Beds with Eramosa-like characteristics (i.e. bituminous and laminated) were also discovered in cliff exposures at Driftwood Cove (east of Tobermory), apparently within the Guelph Formation interval.

Zinc mineralization occurs in Amabel and/or Guelph Formation strata northwest of Umbrella Lake (NTS 41H/3, UTM 467700mE, 5008550mN), in the north-central portion of the map area (Caley 1945; Liberty and Bolton 1971). At this showing, sphalerite predominantly occurs as void-filling mineralization

(e.g. fossil molds, vugs, fractures). No other sulphide mineralization is known in the northern Bruce Peninsula area.

Only limited oil and gas exploration has been conducted on the northern Bruce Peninsula. During the 1950's, three unsuccessful exploration wells were drilled (all to Precambrian basement) in this area (Habib and Trevail 1984). The only producing field on the Bruce Peninsula is the now abandoned gas field at Hepworth, 12 km south of Wiarton, which produced gas from the Ordovician Simcoe Group (Bailey and Cochrane 1984). Pinnacle and patch reefs of the Guelph Formation are major producers of gas in southwestern Ontario (Trevail *et al.* 1987); however, to date, neither oil nor gas have been discovered in the Guelph Formation (or any other strata excepting the Ordovician at Hepworth) on the Bruce Peninsula (Liberty and Bolton 1971).

The creation of a new National Park, covering much of the northern Bruce Peninsula area, was recently announced. Although this park will probably restrict future exploitation of potential mineral resources within its boundaries, a thorough understanding of the geology of the park area will aid in resource identification and evaluation elsewhere in southern Ontario.

ACKNOWLEDGMENTS

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069. Structural Geology of Prince Edward County, Southern Ontario

G.H. McFall[1] **and Owen L. White**[2]

[1]Geologist, Paleozoic/Mesozoic Geology Subsection, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

[2]Chief, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

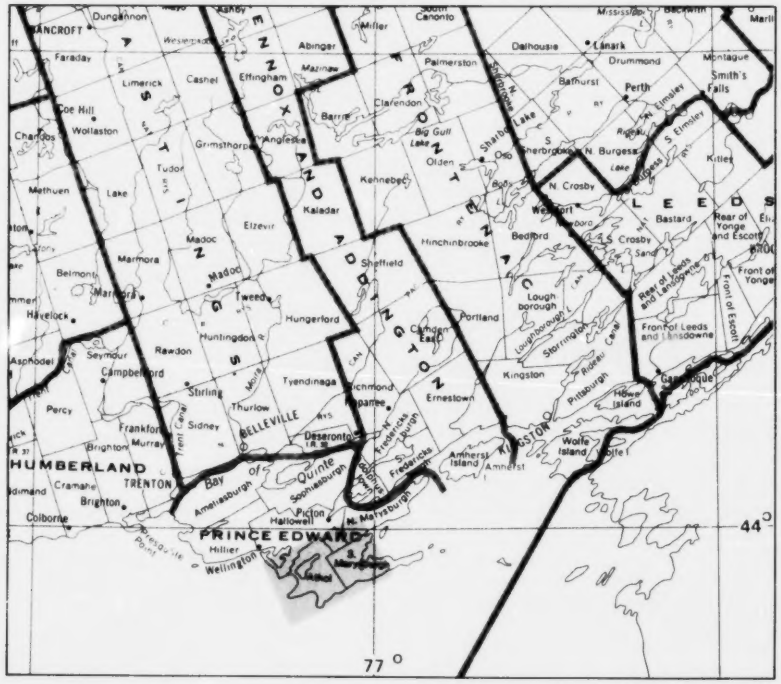
Detailed mapping of the structural features in the southern part of Prince Edward County has been undertaken by the Ontario Geological Survey as the initial contribution to a multi-year program investigating neotectonics in Eastern Canada. This research is being organized by the Multi-Agency Group for Neotectonics in Eastern Canada (MAGNEC). Other agencies involved in the project include: Atomic Energy Control Board, Geological Survey of Canada, Ontario Centre for Remote Sensing, Ministry of Natural Resources and Ontario Hydro.

The Ontario Geological Survey contribution to this study is centred on the field identification of geologic features which may indicate neotectonic activity. Neotectonic features are defined as structural features indicating movement which can be clearly demonstrated to have occurred since the disappearance of the last ice sheet (approximately 10 000 years ago in the Prince Edward County area). Thus, these features could include faults, stress relief phenomena (pop-ups), domes and off-set strata between adjacent bedding planes.

This year's activity concentrated on the southern portion of Prince Edward County in the Bay of Quinte area. Located south of the town of Belleville, the field area encompassed approximately 100 km^2 with the area bounded by the Lake Ontario shoreline, Latitude 43°56'N and Longitude 77°12' to 77°03'W. Resource assistance for this work was supplied by Ontario Hydro and the Tweed office of the Resident Geologist, Ontario Ministry of Northern Development and Mines.

GENERAL GEOLOGY

Paleozoic strata in the southern part of Prince Edward County are Middle Ordovician in age, with the Verulam and Lindsay Formations exposed. These overlie other units from the Simcoe Group, specifically, the Bobcaygeon and Gull River Formations, which in turn overlie a thin veneer of reworked basal material and Precambrian basement rocks. Total Paleozoic cover in the Belleville area amounts to approximately 210 m (Carson 1981). Mapping of the area by Carson (1981) suggests that the Paleozoic geology is relatively simple. Detailed mapping was subsequently undertaken in adjacent eastern Ontario, east of the Frontenac Axis (an exposed Precambrian high which trends northward through the Kingston area) (*see* Williams and Wolf 1984). This work included a redefinition of the Bobcaygeon/Gull River



LOCATION MAP

Scale: 1:1 584 000 or 1 inch to 25 miles

Contact and it suggested that Carson's (1981) interpretation of the Belleville area requires further revision. The Verulam Formation, as most recently defined, (from eastern Ontario, *see* Williams, in preparation) consists of interbedded microcrystalline to coarse-crystalline limestone with interbeds up to 15 cm thick composed of dark grey calcareous shale. The Lindsay Formation, as recently redefined by Russell and Telford (1983), has two members. There is a lower unnamed member consisting of microcrystalline to coarse-crystalline fossiliferous limestone with undulating shaly partings, and an upper member termed the Collingwood Member which is a black to dark brown, calcareous, organic-rich shale and limestone unit. The Collingwood Member has not yet been identified within the study area.

LINEAMENTS

Neotectonic features are often visible as lineaments on infrared imagery and conventional air photographs. These techniques were used initially to locate possible neotectonic features. Examination of infrared colour imagery, supplied by the Ontario Centre for Remote Sensing, revealed lineaments as narrow as 2 m in width. These are shown by changes in vegetation cover, provided they had a length of several metres. Conventional air photographs were also used to find lineaments, and are better suited to the identification of bedrock features below shallow water.

Most lineaments investigated have turned out to be either glacially induced, such as relict shorelines, beach ridges, or ice scoured flutings, or man-made features such as ditches, furrows, and over-grown drystone walls. As the area was heavily utilized for military training during 1939 to 1945, there are many unidentifiable man-made features.

Several small scale stress relief phenomena, evident as bedrock buckles (or pop-ups), have been discovered. Good finds are located near Gull Bay directly south of Milford (UTM 332800mE/4859100mN) and near the Department of National Defence Station at Point Petre (UTM 329350mE/4857750mN).

Of special interest are open fractures. These unexpected phenomena appear to be tensional features and not solution enhanced joints. These have been recorded in swarms such as near Milford (UTM 334340mE/4866875mN) or as isolated individual features. The fractures exhibit mostly vertical sides, which are up to 20 cm apart. The length of the fractures ranges from several metres to tens of metres. Although they appear to be several metres deep, their full depth is not known. Some appear to be partly filled with surficial material.

An awareness of neotectonic features in southern Ontario has important implications for construction, particularly of critical structures such as nuclear power developments, toxic waste storage facilities, and pipeline construction. A clear understanding of these features through studies such as this, will permit an accurate assessment of this significant construction hazard.

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070. Mid-Ontario Building Stone Project, Muskoka-Parry Sound Area

J.R. Meadows[1], C.R. Fouts[1], and P.G. Telford[2]

[1]Resource Geologist, Industrial Minerals Section, Ministry of Northern Development and Mines, Toronto.

[2]Manager, Industrial Minerals Section, Ministry of Northern Development and Mines, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

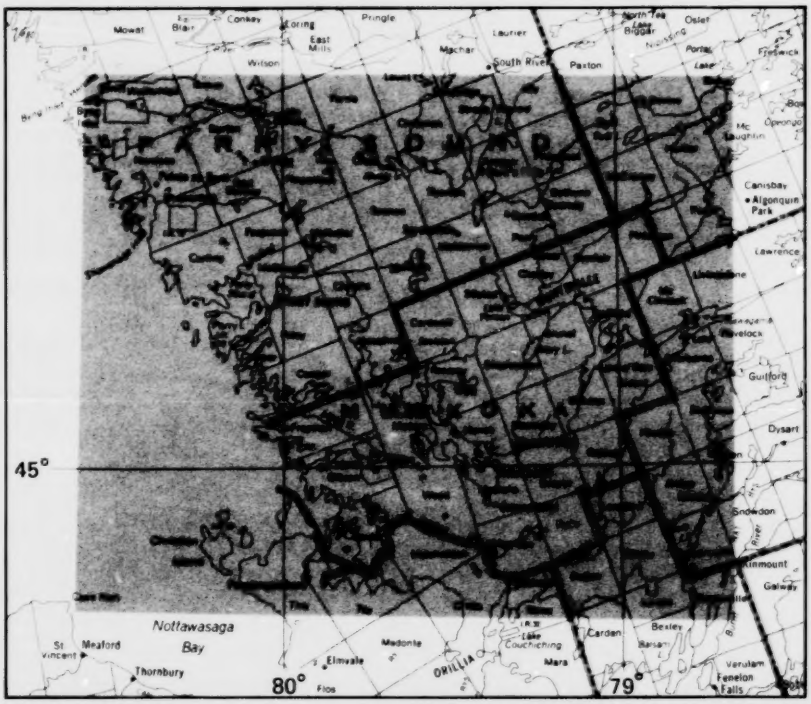
An assessment of the resource potential of the gneissic flagstone quarries of the Muskoka-Parry Sound area (*see* location map) was carried out during the field season of 1987. This study forms a part of the Mid-Ontario Building Stone Project funded by the Canada-Ontario Mineral Development Agreement (COMDA). The goal of this project is to evaluate the dimension/building stone potential of the Muskoka-Parry Sound and Bruce Peninsula areas of Central Ontario (Armstrong 1986). A study of the resource potential of the Muskoka-Parry Sound gneisses was undertaken by a field party of the Ontario Geological Survey in coordination with the Resident Geologist's Office in Dorset of the Ministry of Northern Development and Mines. Chris Marmont and Marcus Johnson from the Dorset office carried out complementary field work on more massive gneisses in the same area.

Geological studies at a number of active and periodically active flagstone quarries in the Muskoka-Parry Sound area were conducted. The mineralogy and localized structural features of these quarries were used to determine geological trends which affect the production of flagstone/veneer products. A second phase of this study documented quarry and masonry techniques used in the production of dimension stone from these rocks.

The study area, approximately 9000 km^2, constitutes a large part of the Muskoka and Parry Sound Districts of Central Ontario. The area also includes small areas of Haliburton District, Victoria and Grey Counties and is covered by NTS map sheets 31/D, 31/E, 41/A and 41/H at 1:250 000 scale. The region is bounded to the north by 46°N, to the east by 78°W, to the west by 80°W, and to the south by 44°N.

GENERAL GEOLOGY

The Muskoka-Parry Sound area of Ontario possesses a complex assemblage of gneissic and migmatitic rocks with minor lithologies of marble and anorthosite. The complexity of these rocks, coupled with low economic potential for metallic mineralization and poor accessibility in some areas, are the main rea-



LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

TABLE 070.1 LIST OF PRINCIPAL QUARRIES

Name	Map Sheet	UTM	Domain	Lithology
Armstrong Quarry	31/d 15	679350E 4982900N	Muskoka	grey gneiss
J.Bacher	31/E 7	671400E 5019400N	Algonquin	red-pink gneiss
T.Boyes	31/E 12	618800E 5050600N	Kiosk	pink gneiss
F.Boothby	31/E 6	651300E 5024350N	Algonquin	grey gneiss
Central Ontario Natural Stone	31/D 10	671650E 4957300N	Muskoka	black, grey, blue, pink gneiss
J.Cotterchio	31/E 7	661850E 5037650N	Algonquin	pink gneiss
M.Fraser	31/E 7	662300E 5038250N	Algonquin	pink gneiss
McFadyen	31/E 6	651750E 5024100N	Algonquin	grey gneiss
Mill Lake Stone Quarry	41/H 7, 8	577010E 5023600N	Parry Sound	grey and pink gneiss
R.Murdy	31/E 7	662200E 5038150N	Algonquin	pink gneiss
Reed Quarry	31/E 6	651450E 5024500N	Algonquin	grey gneiss

sons why this part of the Grenville Province remains mapped in localized areas only. Previous maps from unrelated projects covering limited areas in detail are Satterly (1956), Van Berkel and Schwerdtner (1986), Bright (1987), and McRoberts and Tremblay (this volume); with the following completed on a regional scale: Satterly (1943), Hewitt (1967), and Davidson *et al.* 1982).

The study area lies in a region defined as the Central Gneiss Belt of the Grenville Province. These Middle Proterozoic rocks possess K-Ar ages which cluster between 1150 and 950 Ma (Stockwell 1973). The major lithology is a grey biotite-quartz-feldspar gneiss, which commonly contains pink pegmatites. Less common is hornblende gneiss, marble and a host of plutonic intrusives, the most notable being anorthosite. The entire area has been metamorphosed to upper amphibolite and granulite facies and most outcrops show evidence of extreme folding, faulting, and shearing.

A significant amount of work on the southwestern region of the Central Gneiss Belt has been completed by Davidson and co-workers (Davidson and Morgan 1981), who have defined structural domains and subdomains based on distinctive lithology, metamorphism, and structural signatures. The study area occurs in the Britt, Ahmic and Muskoka Domains and part of the Algonquin Domain.

Davidson has shown that the domains are stacked as a result of northwestern directed ductile thrusting, which occurred deep in the crust. Evidence for this includes tectonic zones, well developed stretching lineation, which plunge generally to the southeast, microscopic kinematic indicators and juxtaposition of different rock assemblages of differing metamorphic grades in adjacent areas.

FIELD STUDY

Sixteen active and periodically active quarries in the Muskoka-Parry Sound region were examined. The principal quarries are shown in Table 070.1. Geological information established for each quarry includes the following:

1. quarry plan map identifying quarry dimensions, structural details and available reserves
2. macroscopic and microscopic properties of the mineralogy in the property
3. mineralogical and structural trends of gneisses which promote splitting for flagstone production

Ribbon lineation and quartz rodding are prominent in many of the quarries.

A second phase of this study involved documentation of quarrying methods including all stages from initial stone removal to finishing. Methods of splitting the stone varied from drilling, hand tooling with rock hammers to hydraulic splitters and blasting. Masonry techniques were somewhat localized and involved examination of chisel shapes for both breaking and shaping stone. A photographic record also augmented the collection of building stone construction techniques and finished structures, which included wall cladding, steps and walkways, fireplaces and driveways.

ECONOMIC GEOLOGY

Flagstone is used widely throughout Ontario. This commodity, as found in the Muskoka-Parry Sound region, has the advantage of displaying colourful and variable textured surfaces and has been used in many buildings and landscape projects. Current products from many of these quarries are mainly flag (2 to 5 cm thick gneiss and mylonitized granites) and veneer stone (8 to 10 cm thick gneiss). Residential construction has utilized many of these products in fireplaces (zero clearance types), walkways, steps, driveways, hearths, mantels, floors, and interior and exterior wall cladding (flagstone uses). Veneer is used in retainer walls, wall cladding and fireplaces, including mantels and hearths.

FUTURE WORK

Assessment of Algonquin quarries will continue in 1987. A study of product options and applications will be continued for these quarries as well as other localities with similar lithologies. A report on the flagstone gneisses is scheduled for publication the following year.

ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance of Dave Villard, Chris Marmont, Marcus Johnson, and Mary Garland of the Resident Geologist's Office in Dorset and Max Vos of the Engineering and Terrain Geology Section, Ontario Geological Survey in Toronto. Quarry owners, operators and stonemasons provided invaluable information for this study.

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GEOPHYSICS/GEOCHEMISTRY PROGRAMS

071. Summary of Activities 1987, Geophysics/Geochemistry Section

R.B. Barlow

Section Chief, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

GEOPHYSICAL PROGRAM

During the 1987 field season, the Night Hawk geophysical test range near Timmins, Ontario, was utilized for testing, research, and instruction purposes by personnel from industry, universities, and government. Section staff, together with personnel from Geoprobe Limited of Toronto, carried out field work using the new, scaled down Maxiprobe EM system. The test range was used to demonstrate Canadian geophysical equipment to delegates from 26 countries as part of the Exploration '87 field school held in September.

The second year of a research project to investigate the potential for detecting and tracing conductive strata in Precambrian rocks overlain by thick Huronian stratigraphy, in the Moose Lake sub-basin area west of Cobalt, has been initiated (Hanneson and Huxter, Article 073, this volume). Field testing undertaken during the early part of the season was directed toward analysis of the EM noise conditions, in the vicinity of the town of Cobalt. Late season activities included surveying with ground transient EM equipment in Coleman and Firstbrook Townships. Further computer modeling was undertaken for the purpose of improving existing interpretation techniques.

A gravity survey of the Iroquois Falls-Lake Abitibi area (7200 km^2) was undertaken during the 1987 field season to aid in the regional subsurface geological interpretation of a complex stratigraphic succession of komatiitic, tholeiitic, and calc-alkalic volcanic rock group (Gupta and Johnstone, Article 074, this volume). Approximately 2000 gravity stations were established by an eight-man field party during the summer months. Interpretation of the gravity data will aid in determining the geometry of technological units, as well as the depth of infolding and large structural features of this portion of the Abitibi Belt.

Three airborne electromagnetic-magnetic surveys, covering areas of high mineral potential, were completed during late 1986 and 1987. Approximately 71 000 line kilometres of data were acquired, in areas centred on the northern municipalities of Dryden, Timmins, and Wawa (Barlow, Article 072, this volume). The survey in the Dryden area was completed as part of the Canada-Ontario Mineral Development Agreement. The surveys in the Timmins and Wawa areas were completed under a new five-year Airborne Survey Program, established by the Ministry of Northern Development and Mines and financed from the Northern Development Fund.

GEOCHEMISTRY PROGRAM

The fourth year of a reconnaissance till sampling project, which is being carried out in cooperation with the Engineering and Terrain Geology Section of the Ontario Geological Survey, and forms part of the Black River-Matheson (BRIM) Program, will continue through the Winter of 1987/88 (Steele and Baker, Article 075, this volume). The sampling, largely completed by deep rotasonic drilling, is of particular value in the area due to the paucity of outcrop. Both regional Quaternary (glacial) stratigraphy and a till geochemistry data base are being established from the results. Thus far, the presence of two glacial packages under the Matheson till have been indicated from the detailed stratigraphic record preserved in unconsolidated cores recovered by drilling. Clastic sections of the core are subjected to heavy mineral separation so that independent gold grains may be counted and examined for their size and shape to help in determining their providence.

A regional geochemical survey in the Goudreau Lake area, situated 40 km northwest of Wawa, Ontario, was completed during the summer season (Fortescue and Stahl, Article 076, this volume). The area is being actively prospected for gold and this survey will supply much needed orientation data over the 500 km^2 area which will be combined with other geoscience data bases developed simultaneously. Sampling was carried out by using a unique coring technique which minimizes the inclusion of lake sediments which have been modified during technological time. A total of 358 sample sites were established which increased

the sample density tenfold with respect to a previous reconnaissance data base established by the Canada-Ontario URP program in 1979.

A regional geochemical survey in the Wart Lake area, situated 74 km north of Sault Ste. Marie, Ontario, was completed during the late Summer (Fortescue and Stahl, Article 077, this volume). This survey is the first phase of a three-year project carried out as part of the Canada-Ontario Mineral Development Agreement (COMDA). Water and lake sediment core samples (392 samples) were collected from an area of 375 km^2. As in the Goudreau Lake area, sampling was carried out by using a unique coring technique which minimizes the inclusion of lake sediments which have been modified during technological time. This survey will provide a summary of the geochemical behaviour of elements of importance to mineral exploration in the area.

072. Recent Airborne Electromagnetic-magnetic Surveys in Northern Ontario

R.B. Barlow

Section Chief, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

INTRODUCTION

A total of three Airborne surveys were completed during 1987. In all, approximately 71 000 line kilometres of electromagnetic and magnetic survey data were acquired and compiled during the year. A survey in the Dryden area (Location Map A) consisting of approximately 19 000 line kilometres was released May 26, 1987 (OGS 1987). The survey data was acquired as part of the Canada-Ontario Mineral Development Agreement (COMDA) in order to increase the geoscience data base in areas of the Province having exploration potential.

On March 10, 1987, the Ministry of Northern Development and Mines announced a new $10 million, five-year Airborne Geophysical Survey Program for Northern Ontario. The airborne survey program is being financed through the Northern Development Fund and managed by the Ontario Geological Survey.

To date, approximately 51 000 line kilometres of data have been acquired and compiled over two areas centred on the northern municipalities of Timmins and Wawa (Location Maps B and C). These surveys are scheduled for release during the 1987/88 fiscal year.

SURVEY INSTRUMENTATION

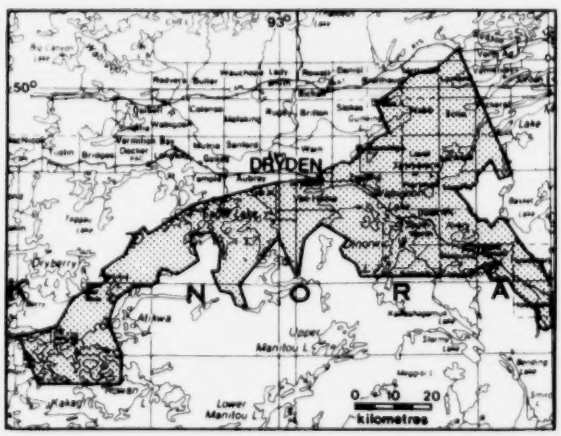
The GEOTEM(R) system, owned and operated by Geoterrex Limited of Ottawa, was used to acquire the electromagnetic data over the Dryden and Timmins areas. The survey platform was a CASA C212-200, twin turboprop short takeoff and landing (STOL) aircraft having a six strand, three turn, horizontal transmitter loop installed around the extremities of the plane and a sensor mounted in a towed bird. A Scintrex single-cell, split-beam, cesium vapor magnetometer was mounted in a stinger on the tail of the aircraft. Instrument configuration within the craft consisted of the digital receiver and transmitter circuits, a microprocessor and tape drive for data storage as well as the magnetometer console and positioning equipment.

The primary electromagnetic field about the aircraft is created by a series of discontinuous sinusoidal (half sine) current pulses which are fed through a three turn loop. The duty cycle is composed of 1050 microseconds of "on time" followed by 2280 microseconds of "off time" which is utilized to sample the resulting transient produced by the ground response. During the "on time", the peak current through the loop is 600A resulting in a dipole moment of 4.5×10^5 Am^2. The receiver sensor coil is mounted vertically, with the axis in the direction of flight, in a bird towed on a 135 m cable approximately 40 m above the ground when the aircraft survey altitude is 120 m.

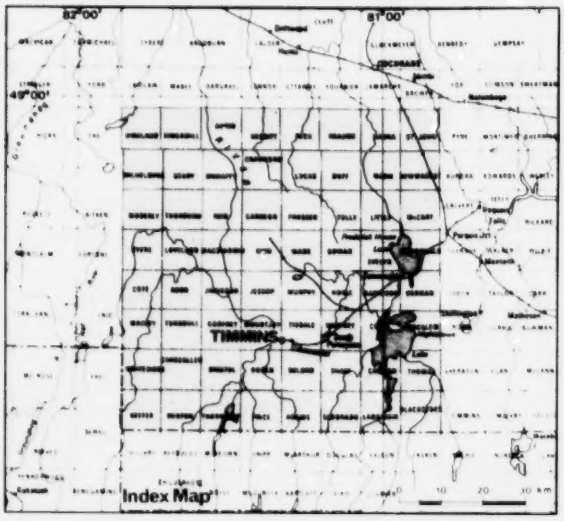
The transient resulting from the ground response is sampled six times a second over twelve gates whose centres and gate widths can be software selected over the entire range of "off time". Post-flight processing normally reduces the noise level to about a 20 ppm envelope.

The DIGHEM(R) system, owned and operated by Dighem Surveys and Processing Incorporated, was used to acquire the electromagnetic data over the Wawa area.

This survey platform consisted of an Aerospatiale AS 350B ECYR EYUK (Squirrel) helicopter with a Turboméca Arriel (592 hp) engine having an 800 kg cargo sling capacity. Both transmitter and receiver coils are mounted in a tubular bird which is towed below the helicopter and approximately 30 m above the ground. Each TX-RX coil-pair are separated by an 8 m distance. A Scintrex single-cell, split beam cesium vapor magnetometer was towed below the helicopter and above the EM bird. The coil orientations consist of one vertical coaxial operating at 900 Hz and two horizontal coplanar coil-pairs operating 900 Hz and 7200 Hz frequencies. The instrument configuration within the helicopter consists of re-



LOCATION MAP A Scale: 1:1 584 000 or 1 inch to 25 miles



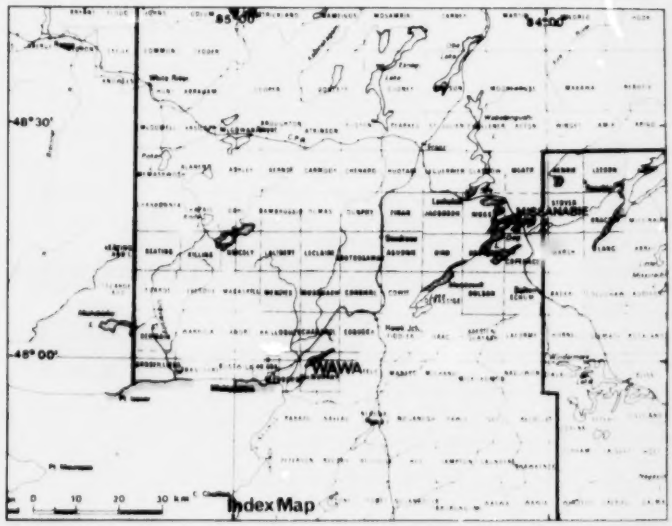
LOCATION MAP B Scale: 1:1 584 000 or 1 inch to 25 miles

ceiver and transmitter consoles, a digital data acquisition system, magnetometer console and various position equipment.

The primary electromagnetic field about the bird is created by a continuous sinusoidal wave form and the secondary field is measured in the presence of the primary field by a phase component measuring system. The intensities of the inphase and quadrature components of the secondary field are measured continuously during flight at pre-described frequencies and coil orientations and are given as fractions of the primary field strength.

The dipole moment of the transmitter is 225 Am^2 at 900 Hz and the skin depth of the system is 290 m at 900 Hz and 103 m at 7200 Hz for a 300 ohm-m half space. The effective exploration depth as established at the Night Hawk Lake test range is approximately 150 m.

The sampling rate for both electromagnetic and magnetic data is ten samples per second. Noise levels for the electromagnetic data are less than 1 ppm in quiet air bursting to between 1 and 3 ppm in acceptable flying conditions.



LOCATION MAP C Scale: 1:1 584 000 or 1 inch to 25 miles

RESULTS

The maps are prepared with a photomosaic base at a scale of 1:20 000 using Ontario Ministry of Natural Resources 1:15 840 scale aerial photography. The photos were laid down using a Universal Transverse Mercator projection format constructed from scaling down 1:50 000 topography maps.

The flight lines, anomalies, and magnetic contours were superimposed on this base and appropriate legend information was attached. Digital profiles of every flight line were constructed with standard presentation schemes and microfilmed for permanent storage.

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073. The Detection and Mapping of Basement Conductors Under Areas Covered by Thick Huronian Sedimentary Rocks, District of Timiskaming

James E. Hanneson and Ronald S. Huxter

Geophysicists, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

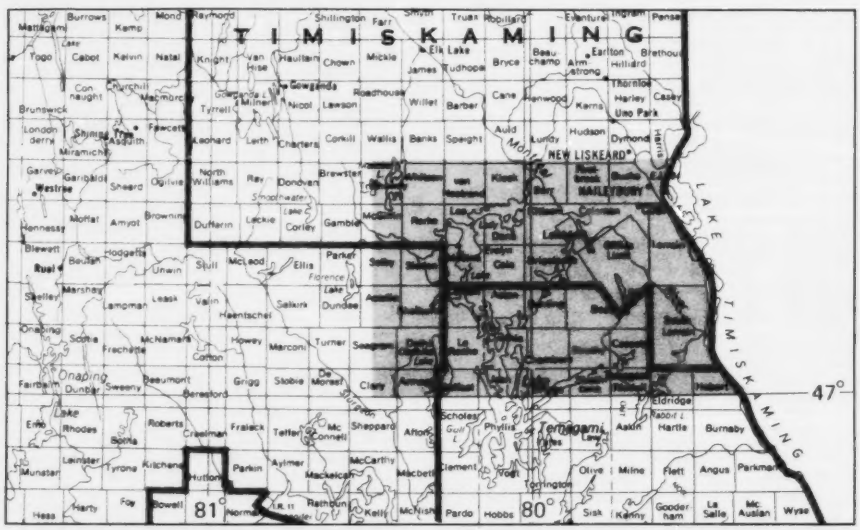
The electromagnetic (EM) surveying project, initiated in 1986, for tracing conductive strata in Precambrian rocks overlain by thick sedimentary cover, continued with additional field testing and computer modeling. The field testing undertaken during the early part of the season was directed mainly toward understanding the EM noise conditions in the vicinity of the Town of Cobalt. Late season field activities included cutting a survey control grid of 100 line kilometres in Coleman and Firstbrook Townships over which EM surveying is presently in progress. The computer modeling was undertaken for the purpose of improving existing interpretation techniques, and the most significant development is the adaptation of software for simulating the time-domain EM response of a rectangular plate in a conductive half-space for all commercially available systems.

SURVEY EQUIPMENT

The Lamontagne UTEM 3 Transient EM prospecting system continues as the main exploration tool for the project. However, existing software (Holladay 1981) was adapted to simulate responses for another wide-band transient EM system, the Geonics Limited's EM-37, and test work with this system will probably occur in the future.

EM NOISE STUDIES

Feasibility testing conducted in 1986 yielded significantly noisier profiles than is commonly encountered in other test areas such as the Night Hawk Geophysical Test Range near Timmins. Measurements were subsequently made at various locations throughout the area to determine the nature of the ambient signals in the absence of a primary transmitter signal. At a given site, the UTEM 3 receiver was programed to make 25 measurements, each of which was the



LOCATION MAP

Scale : 1:1 584 000 or 1 inch to 25 miles

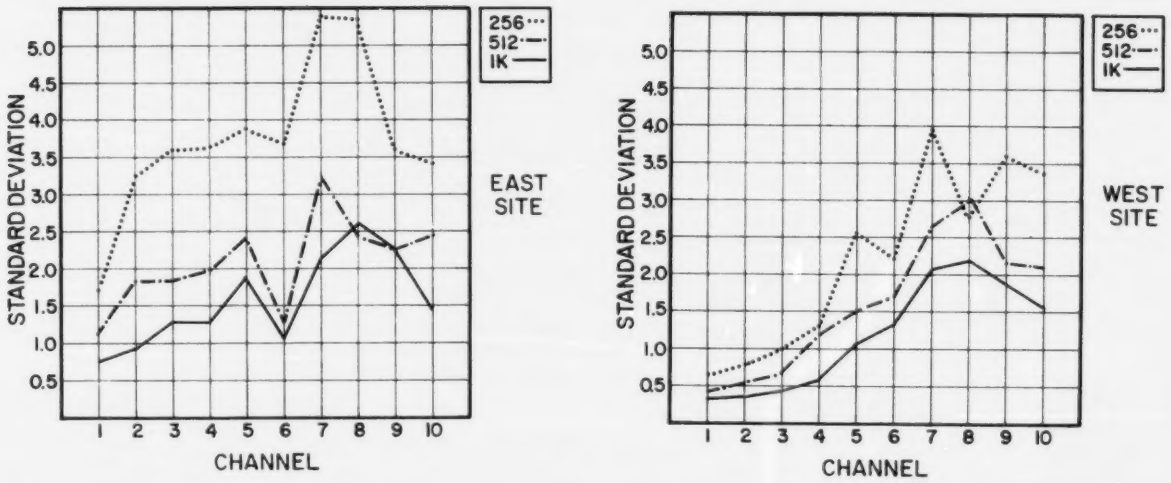


Figure 073.1. *Standard Deviation of Twenty-five readings (Hz) each of which averages 256, 512, and 1024 cycles. Late-time noise is considerably worse near Cobalt (a) than at a site seven kilometres more remote (b).*

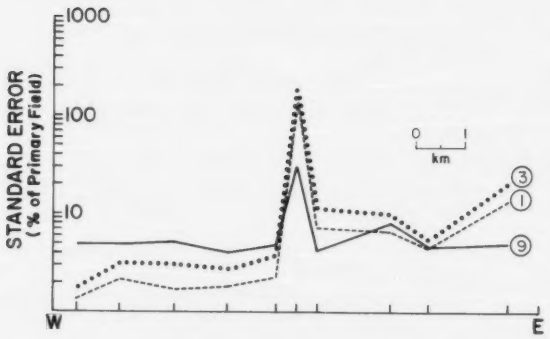


Figure 073.2. *East-west profile of noise show progressive worsening of late-time noise toward the town of Cobalt. The central spike, which occurs over a natural gas pipeline and is serious but highly localized.*

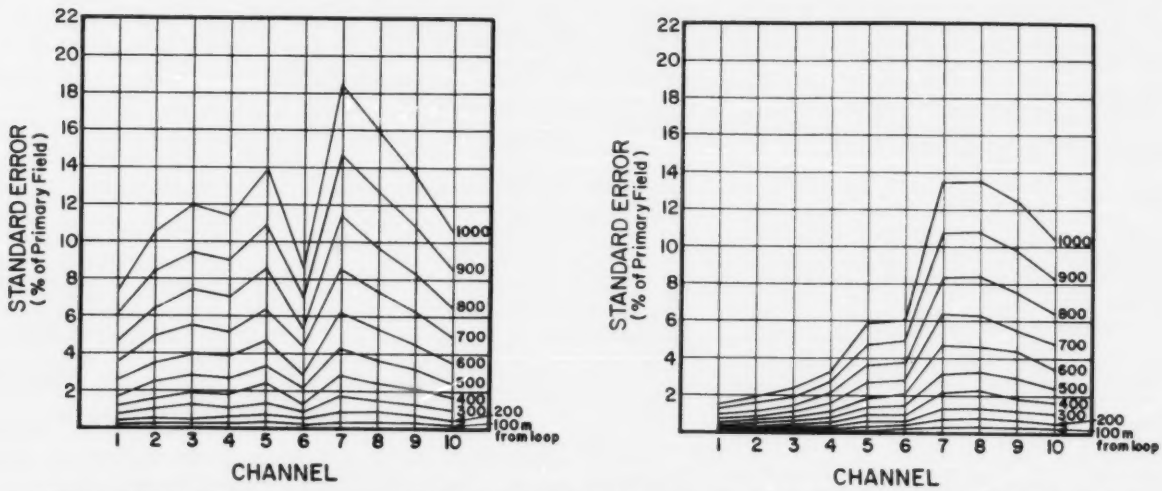


Figure 073.3. *Noise spectra normalized to primary field values at various distances from a 1 km x 1 km transmitter loop for the two sites in Figure 073.1. Figures 073.3a and 073.3b pertain to Figures 073.1a and 073.1b respectively.*

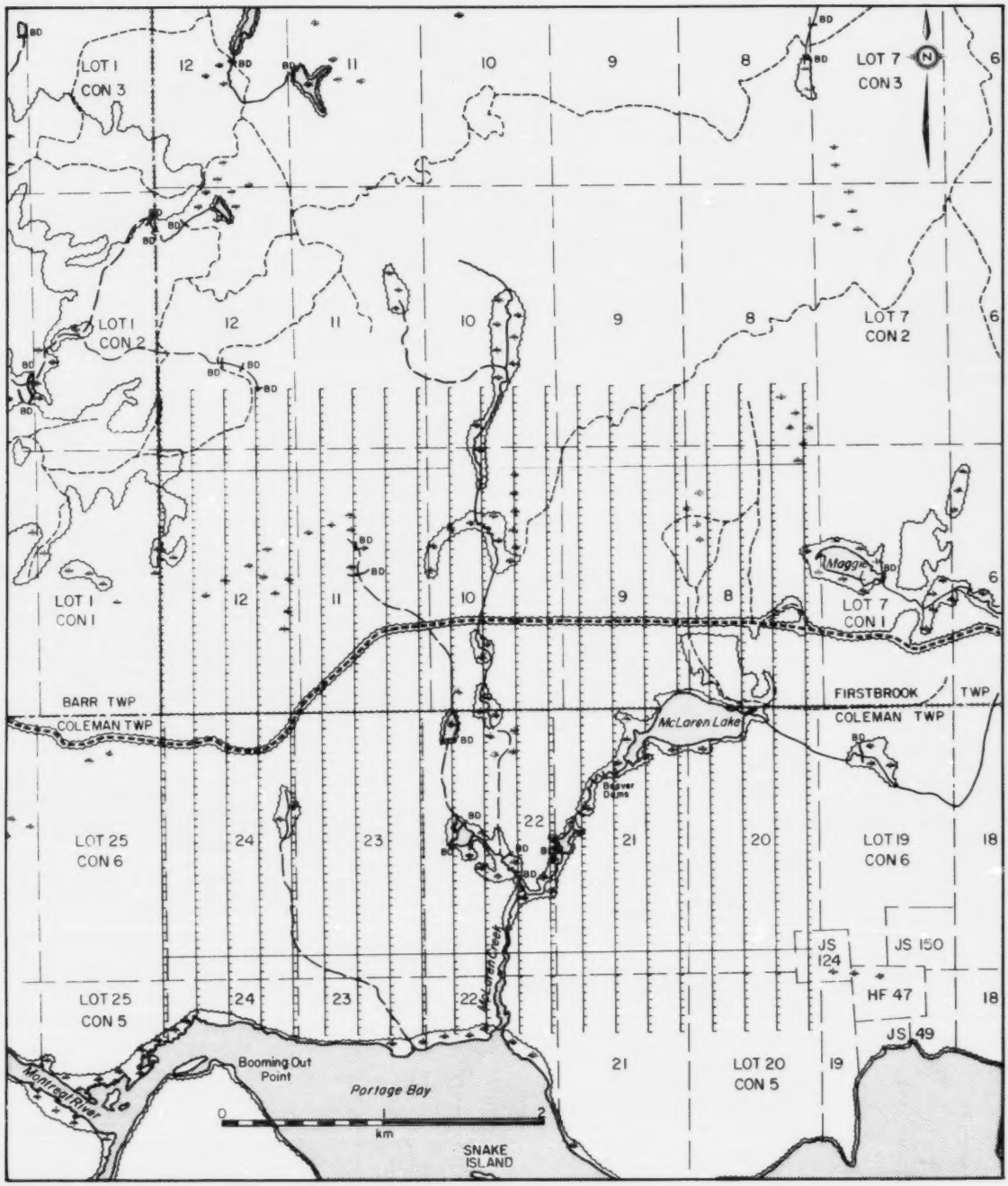


Figure 073.4. *Idealized line locations for survey control grid.*

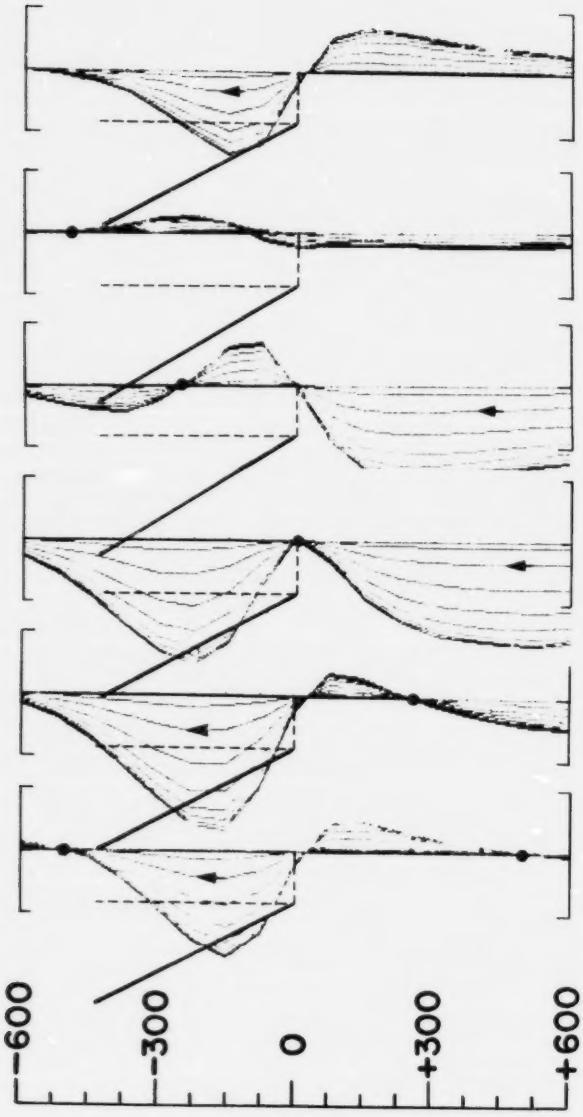


Figure 073.5. *Example of changes in profiles due to changes is source-target geometry. Dots indicate locations of transmitter wire. Vertical scale bars range from -20% to +20% of primary field, continuously normalized.*

result of three different stacking intervals: 256 cycles, 512 cycles, and 1024 cycles. Each set of 25 readings was then used to compute a standard deviation and a standard error for the different stacking intervals, which could then be compared from site to site. Figure 073.1 illustrates standard deviations for all channels and the three stacking times at two sites in the area. Figure 073.1a illustrates results from a site 3 km west of the Cobalt town centre and is much noisier in the late time channels (one to four) than results given in Figure 073.1b from a site 7 km further west. The latter results compare favourably with results of the same test performed under ideal conditions at the Night Hawk Test Range. These data also confirm that noise levels are reduced by increasing the number of cycles stacked. From the knowledge that noise decreases as the square root of the cycles stacked, the three- to four-fold worsening of noise at the eastern site suggests that achieving noise levels comparable to the west site would require ten times as much averaging. That the noise is cultural in origin is inferred from the results of an east-west traverse through the area (Figure 073.2). Except for a spike in the immediate vicinity of a natural gas pipeline (profile centre), a progressive worsening of conditions eastward toward the town is apparent especially at late times. Figure 073.3 normalizes the data in Figures 073.1a and 073.1b (1024 stack) to the primary field at various distances from a (1 by 1 km) transmitter loop and allows for a prediction of the required number of averaged cycles to achieve a given standard error at a given site under the noise conditions described in Figure 073.1.

SITE SELECTION

A 4 by 4 km area in Coleman and Firstbrook Townships was selected on the basis of favourable EM noise conditions and anticipated favourable geology. Precambrian basement rocks are exposed through a window in the Huronian cover near Maclaren Lake and some airborne and ground EM conductors have been detected in the vicinity. A position control grid is being established comprising some 100 km of line and is illustrated in Figure 073.4.

COMPUTER MODELS

PLATE IN A RESISTIVE HOST

Additional modeling was conducted using a program, described by Hanneson and Huxter (1986), which computes the transient EM response of a plate in free space. Because stationary large-loop systems, such as the UTEM 3, produce anomalies over dike-like responders which are strongly dependent on the loop-target geometry, several model responses were computed in order to catalogue anomaly shapes resulting from loops at different locations. For example, Figure 073.5 illustrates the response of a shallow-dipping plate at 125 m depth for various locations of the transmitter loop. One hundred and twenty such profiles were produced as part of the developing interpretation database and were organized according to loop location, plate dip, and plate depth.

PLATE IN A CONDUCTIVE HOST

Due to the greater bandwidth of some modern transient EM systems, measurement times can be early enough that the host rocks in a survey area will always give strong responses. In the absence of responses from very conductive local inhomogeneities, such as dikes, these responses are expected to be useful for conductivity imaging using the method of MacNae and Lamontagne (1987). In the presence of dike-like responders, profiling techniques will be exploited to infer locations, attitudes, and depths for basement features, but accurate, comprehensive suites of modeling curves will be required. To this end, a computer program described by Hanneson and West (1984) was adapted to generate UTEM responses for a plate in a conductive host. One suite

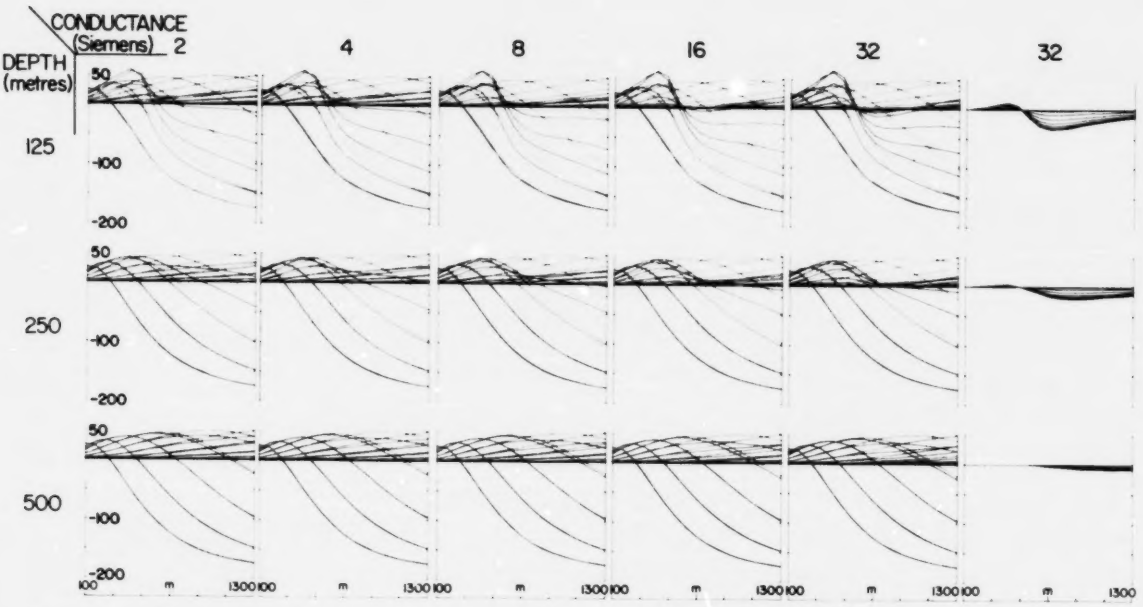


Figure 073.6. *UTEM (Hz) responses of plates in a 1000 ohm-m half-space (solid) exhibit anomalous differences from the host response (dotted). At late-times and high plate conductance the differences are similar to the response of a plate in free space (column at right). At intermediate times and all plate conductances the differences are enhanced by the galvanic effect. Differences are attenuated at early times (blanking effect) due to non-instantaneous propagation of the primary field in the host. Loop offset distance is 500 m.*

of curves for a vertical plate in a half-space was produced on a DEC Professional 350 microcomputer and is presented in Figure 073.6. The results illustrate many physical effects commonly observed by transient EM surveying, and include early-time galvanic effects and late-time local induction, with the resulting effects of enhancement, blanking, and time-delay on the anomaly amplitudes. These profiles represent only a small portion of a comprehensive interpretation base, but demonstrate an important modeling capability. The suite is presently being expanded to study the effects of other parameters.

CONCLUSIONS

The feasibility stage of the project is complete and indicates that useful information will be obtained from a wideband EM survey. Noise studies in the area suggest that surveying within about 3 km of the Cobalt town centre will encounter poor but not necessarily unacceptable noise conditions. The source of the late-time ambient noise remains undetermined and will be monitored while surveying. The validity of computer models for interpreting the wideband EM response of a conductive dike in a conductive host is established, and expanded sets of model curves will be valuable for the accurate interpretation of survey data.

FUTURE ACTIVITIES

The linecutting is complete and will be followed by UTEM 3 surveying in the Fall of 1987. Magnetometer and VLF-EM surveying may be included. Following an examination of the data, efforts will be made to expand the interpretational database and consideration will be given to extending the survey area.

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074. A Gravity Survey in the Iroquois Falls-Lake Abitibi Area, District of Cochrane

V.K. Gupta[1] and R.M. Johnstone[2]

[1]Geophysicist, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

[2]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The gravity surveying of the Abitibi Greenstone Belt is an ongoing multi-year study to map and define the deeper geological, lithological, and structural characteristics of the belt based on its gravitational field. These studies will improve our understanding of the evolution of the Abitibi Greenstone Belt and its associated mineral deposits.

Part of this year's survey area was mostly inaccessible and largely unmapped. To make the helicopter use cost-effective and to provide geological input to the gravity field work, the gravity survey was conducted in conjunction with geological mapping. The gravity and geology traverses by helicopter, as well as gravity stations site selection, were jointly planned. A brief summary of the geology and gravity survey procedure is presented below.

LOCATION

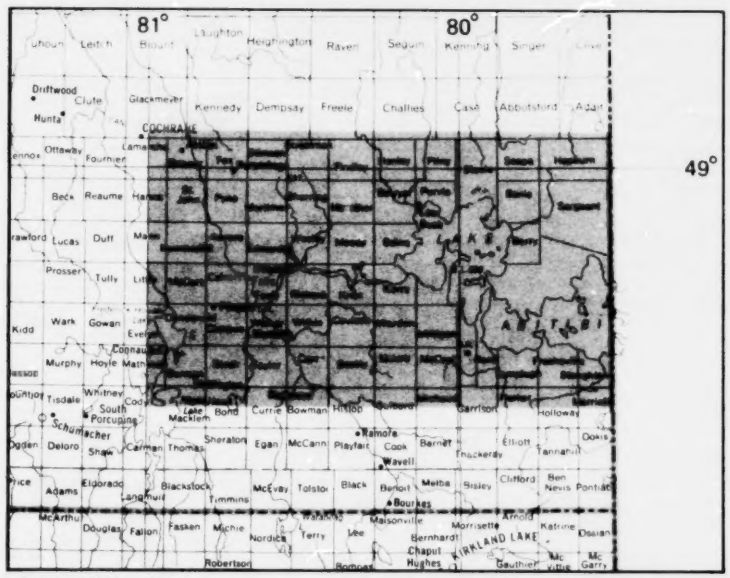
The gravity survey is bounded by Latitudes 48°30′N and 49°05′N, and Longitudes 79°30′W and 81°00′W, covering an area of approximately 7200 km^2. Access by motor vehicle in the region is provided mainly by Highways 11 and 101 which are connected to various lumbering, mining, resource, and recreation access roads. The eastern half of the area is primarily occupied by Lake Abitibi while the central part of the area is largely inaccessible. Access to remote areas was provided by a Bell Jet Ranger 206B helicopter on floats.

GENERAL GEOLOGY

Centrally located in the Abitibi Greenstone Belt (Abitibi-Wawa Subprovince) of the Superior Province, the survey area is predominantly underlain by mafic metavolcanics and metasediments (Figure 074.1) of low metamorphic grade (Prehnite-pumpellyite facies). Ultramafic, intermediate, and felsic metavolcanics are present, particularly in the southern half of the region, but are less common.

Most of the strata have a subvertical dip and strike between 90° and 120°; however, moderately shallow dips and east-northeast and north strikes are more common in the western Lake Abitibi area. The deformation pattern in the southern half of the survey area is characterized by upright, tight or isoclinal, doubly-plunging folds trending east-west, superimposed by open north- or northeast-trending folds (Johnstone and Trowell 1985; Jensen and Langford 1983).

The oldest rocks recognized in the region are the calc alkalic lavas and pyroclastic rocks of the Hunter Mine Group, representing the uppermost member of a volcanic cycle. This volcanic cycle is the second of three recognized in the Kirkland Lake area (Jensen and Langford 1983; MERQ-OGS 1983) and is characterized by a stratigraphic succession of komatiitic, tholeiitic, and calc alkalic volcanic rock groups. Komatiitic and tholeiitic volcanic rocks of the Stoughton-Roquemaure Group, the basal member of a successive volcanic cycle, disconformably overlies the Hunter Mine Group in the south-central part of the



LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

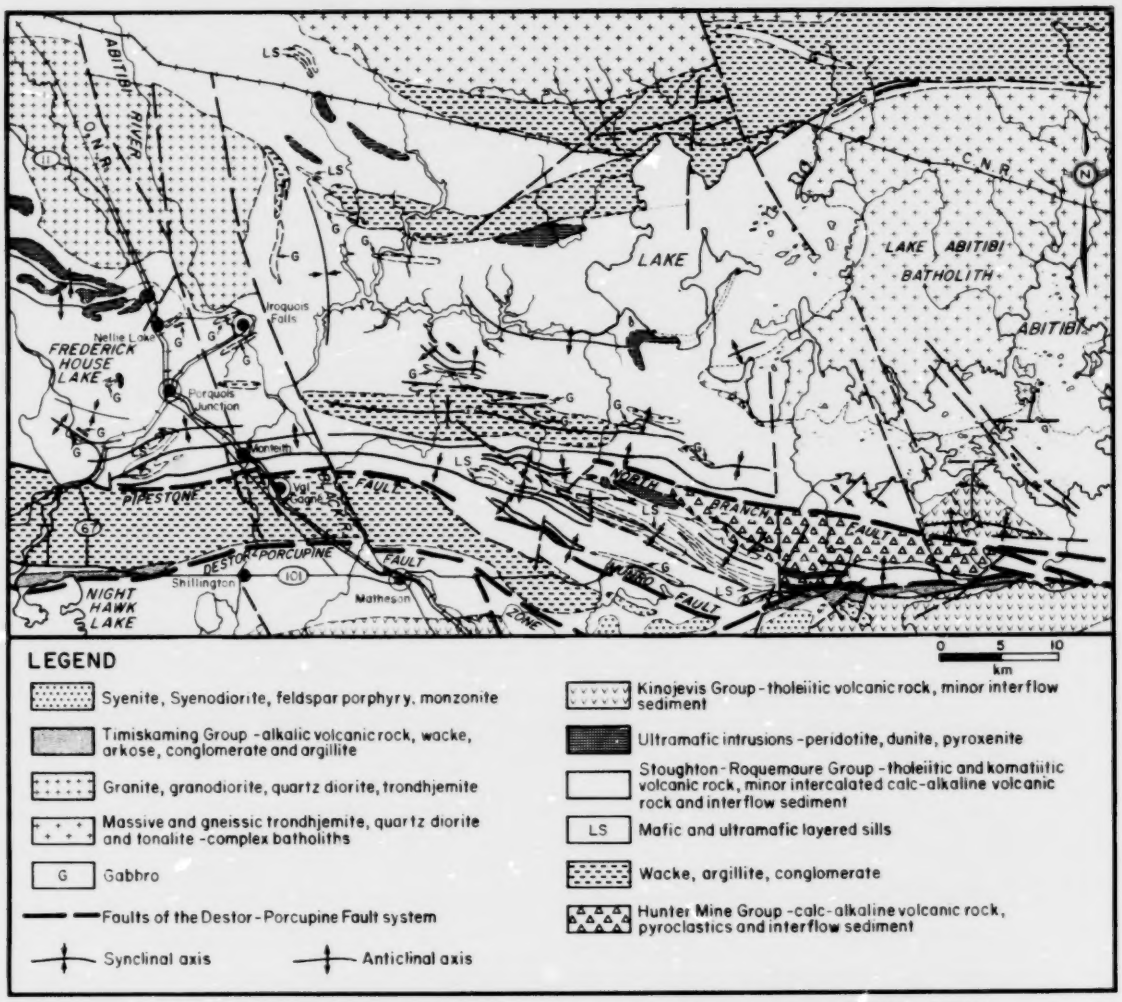


Figure 074.1. *Generalized geology of the western Lake Abitibi region, after MERQ-OGS (1983).*

region. This volcanic cycle stratigraphically comprises, from bottom to top, the Stoughton-Roquemaure Group (komatiites and tholeiites), the Kinojévis Group (tholeiites), the Blake River Group (calc alkalic), and the Timiskaming Group (alkalic). The Kinojévis Group is known to occur only in the southeastern part of the survey area coring a triangular syncline and along the southern edge of the area south of the Destor-Porcupine Fault Zone. The Blake River Group is not found in the Lake Abitibi area while the Timiskaming Group, represented by alkalic volcanic rocks and metasediments, disconformably overlies the Stoughton-Roquemaure Group rocks within narrow fault blocks along sections of the Destor-Porcupine Fault Zone. Although it is suspected that the Stoughton-Roquemaure Group is the only volcanic rock group represented in the northern half of the survey area, the lack of exposure here and the absence of komatiites in outcrop makes such interpretation inconclusive. The Stoughton-Roquemaure succession contains thin lenses of felsic volcanic rock, the result in some cases of bimodel calc alkalic-tholeiitic volcanism. Rhyolite and dacite indicated in diamond-drill hole logs from the west-central part of the area could represent these lenses or could be older Hunter Mine Group rocks.

The Stoughton-Roquemaure Group is a submarine volcanic assemblage consisting of massive and pillowed flows and flow breccia. Interflow sediments include pyritiferous chert, fine-grained wacke, argillite, silicic siltstone, and conglomerate. Related mafic and ultramafic sills, including layered sills, are common.

Discordant intrusions in the region include stocks and dikes of gabbro, diorite, peridotite-dunite, peridotite-pyroxenite, syenite, monzonite, granite, trondhjemite, and three diabase dike swarms. Two large felsic intrusive complexes, consisting of massive to gneissic trondhjemite, tonalite, and quartz diorite, occupy most of the north-central and eastern parts of the survey area. Metamorphic grade within a

few kilometres of the intrusive contact rises from lower greenschist to amphibolite facies.

GRAVITY SURVEY

During the 1987 field season, approximately 2000 gravity stations were established by an eight-man field party. Three Lacoste-Romberg gravimeters G-294, G-417, and G-626 were used for the survey. The average gravity station distribution over the entire area was approximately 1 station per 4 to 5 km^2. A station spacing of about 1 to 1.5 km was established for gravity stations along highways and gravel roads. A station spacing of 300 m was employed along a 16 km long, detailed, levelled, gravity profile near Shillington.

The gravity observations were tied to a local base station (#9031 - 87) established at the Nellie Lake motel. This station was in turn tied to the control stations at Timmins, Cochrane, Monteith, and Matheson forming part of the National Gravity Network IGSN 1971, established by the Canada Department of Energy, Mines and Resources, Ottawa. For the purpose of determining the gravity meter drift, the Lacoste-Romberg meters, which are relatively drift-free, were read at a controlled base station every day at the start and end of each gravity traverse.

Due to a limited occurrence of outcrops in the survey area, only a small number of fresh rock samples were obtained for density measurements. Rock identification in the field was also provided by Ken Card of the Geological Survey of Canada.

ELEVATIONS

Vertical control (or elevation) of gravity stations was provided mostly by Wallace and Tiernan altimeters in pairs which were tied frequently to known elevations within 1 to 2 hours. Appropriate corrections for temperature and humidity variations were also applied by the use of motorized Psychrometers. Vertical control of gravity stations on Lake Abitibi was provided by the lake level, with station elevation being recorded as secondary elevation relative to the water level which was determined precisely from nearby bench marks. Geodetic Survey of Canada and the Ontario Ministry of Transportation and Communications bench marks were also used for elevation control along roads. Vertical control along a 16 km long detailed gravity traverse was provided by precise optical levelling between bench marks on Highway 577 north from Shillington.

HORIZONTAL CONTROL

The gravity stations were established at identifiable sites and were located on either 1:15 000 or 1:50 000 scale aerial photographs. The station positions were then transferred onto 1:50 000 National Topographic System (NTS) maps and digitized with a precision of ±25 to ±50 m.

DATA REDUCTION

The gravity survey was carried out to the specifications and procedures of the Gravity Division of the Geological Survey of Canada. The survey data will be processed at the Gravity Division and a Bouguer Gravity map superimposed on the geology will be compiled by the Ontario Geological Survey.

GEOLOGICAL INTERPRETATION

The gravity survey is primarily carried out to study the relationship of the Bouguer gravity field with geology especially in drift covered areas. From an interpretation of the gravity data, the authors will be able to determine the geometry and depth of infolding of metavolcanic-metasedimentary belts and the contact relationship between contrasting lithologic units.

An important aspect of this survey is to identify and locate major faults, including the Pipestone Fault and the Destor-Porcupine Fault Zone, structures significant due to their spatial and likely genetic association to zones of gold mineralization.

The Destor-Porcupine Fault Zone consists of a series of subvertical and east-west trending faults, shears and zones of intense carbonitization and silicification. At least four normal faults splay off the main fault zone, expanding the zone of related faulting up to a width of 12 km. All of these faults are rarely exposed and their extent and precise positions are only approximately known. The gravity survey may be able to detect, probably only indirectly, some of these subvertical faults on the basis of density contrasts between certain lithological units which are associated with some of the faults. For instance, the northern branch of the Destor-Porcupine Fault Zone, in the south-central part of the area, separates a fault block of low density calc alkalic felsic volcanic rock and pyroclastic material (Hunter Mine Group) from high density mafic volcanic rock (Stoughton-Roquemaure Group) to the north. Sections of the Destor-Porcupine Fault Zone containing narrow fault blocks of low density Timiskaming sediment and alkalic volcanic rock along with faults possessing broad zones of alteration or intruded by felsic dikes, may also be indicated by the survey on the basis of density contrast with the mafic volcanics bordering the Destor-Porcupine Fault Zone both to the north and south.

In addition, the contacts of two fault-bounded belts of Porcupine Group sediments (wacke, argillite, conglomerate) north of Matheson, and a large sedimentary belt in the northern half of the survey area will be better defined, and it is suspected that thick interflow sedimentary units may be detected. The gravity survey will also help define the shape and boundaries of the batholiths, syenitic and granitic stocks, mafic and ultramafic sills occurring throughout the Lake Abitibi area.

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075. Reconnaissance Till Sampling Program, Matheson—Lake Abitibi Area, District of Cochrane

K.G. Steele[1] and C.L. Baker[2]

[1]Geologist, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

[2]Acting Supervisor, Quaternary Geology Subsection, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

This project is part of Operation Black River-Matheson (BRIM) which was funded by the Ontario Ministry of Northern Development and Mines.

INTRODUCTION

A reconnaissance scale overburden sampling program in the Black River-Matheson (BRIM) area began in 1984 and is to be completed in 1989. The program is a combined effort of the Geophysics/Geochemistry and the Engineering and Terrain Geology Sections of the Ontario Geological Survey. The sampling, largely completed by deep drilling, is of particular value in the area due to the extensive and thick drift cover. Less than 5 percent of the study area is outcrop and occasional townships are totally devoid of outcrop. The regional Quaternary (glacial) stratigraphy and a till geochemistry data base are being established from the results of the till sampling program. The data and interpretations produced by the program are of practical importance for exploration.

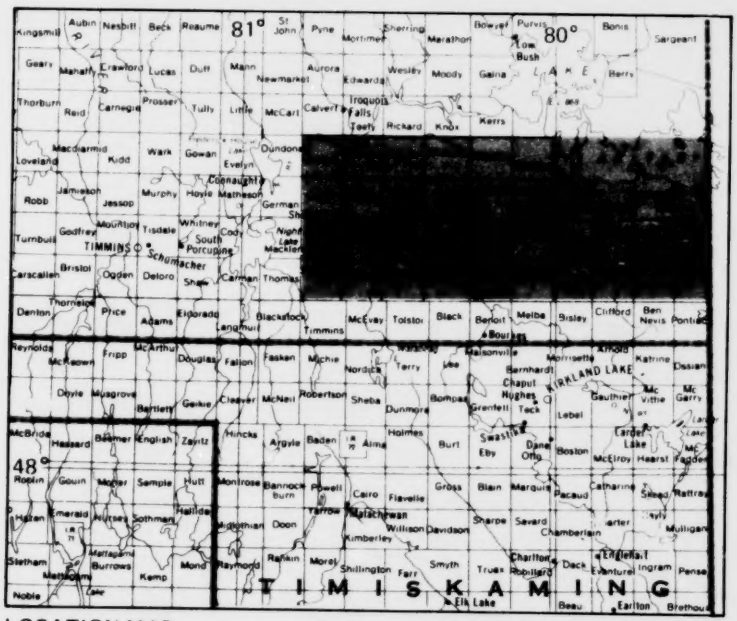
QUATERNARY HISTORY

The study area was deglaciated approximately 10 000 years before the present. The most recent glacial advance was toward 170° azimuth and deposited the Matheson till (informal name). During the latter stages of ice cover, esker systems which trend parallel to the ice flow direction were developed. As the ice front wasted away to the north, it was fronted by glacial lakes Barlow and Ojibway. The existence of these bodies of water resulted in the deposition of thick and extensive glaciolacustrine clay deposits which mask most of the bedrock and lap onto the esker systems.

Overburden drilling in the Matheson area has indicated the presence of two glacial packages under the Matheson till. These older deposits are scattered and usually occur in bedrock depressions oriented at a large angle to the most recent ice flow direction. In the study area, sediments of the package immediately below the Matheson till were deposited from ice which advanced toward 240° azimuth. The lowest package is very restricted in areal extent. The ice flow direction associated with this glacial package is presently unknown. Each glacial package generally consists of varved clays and/or glaciofluvial sands overlying a variable thickness of till.

TILL SAMPLING

Three till sampling methods were used in the program: sonic drilling, backhoe trenching, and hand dug pits. This combination of methods allowed an even distribution of sample sites over the study area. At most sample sites, a complete drift sequence from ground surface to bedrock was exposed and recorded.



LOCATION MAP

Scale : 1 : 1 548 000 or 1 inch to 25 miles

In areas of shallow drift, or when till occurs at surface, trenching was used to search for and sample till. When these areas were near roads, backhoes were used to dig trenches up to 3 m deep. When these areas were only accessible by boat, floatplane, or trail, pits up to 1.5 m deep were dug by hand.

In areas of thick drift, a sonic drill was used because it furnishes a continuous, relatively undisturbed, 88 mm diameter core from all formations including bedrock. The core provides a detailed stratigraphic record for the interpretation of depositional environments and large, complete samples for geochemical analyses.

SAMPLE ANALYSIS

Till samples collected by drill, backhoe, and hand were processed in the same manner. For each sample interval, a 7 to 10 kg bulk sample and two 250 g samples were collected. The bulk till samples were sent for heavy mineral separation. Processing steps were outlined on a flow chart presented in Baker *et al.* (1985). Samples with gold grains visible on the shaker table were further refined by a secondary panning procedure of the heavy mineral concentrate, to obtain the exact number, shape and size of gold grains. Mineralogical examination of the heavy mineral concentrates consisted of a 100-grain point count plus a scan for indicator and accessory minerals. The entire non-magnetic heavy mineral (>3.3 S.G.) concentrate (H fraction) was analyzed for gold and other trace elements by Instrument Neutron Activation Analysis. The concentrate was then split, with half (minimum of 10 g) analyzed for a suite of trace elements. From one of the 250 g samples, the -250 mesh material (G fraction) and -10 mesh material (T fraction) were obtained. These fractions were analyzed for the same suite of trace elements as the H fraction. Major oxide geochemical analyses were done on the T fraction. The second 250 g sample was submitted for till matrix size (texture) analysis and carbonate content determination. By combining geochemical, mineralogical, texture, carbonate and clast data, units can often be separated within a drillhole or correlated between sampling sites.

PREVIOUS SAMPLING

In the period from July, 1984 to September, 1985, two sonic drilling and two backhoe trenching programs were carried out in the study area. The 1984 field work was carried out in the westernmost 16 townships of the BRIM area. In 1985, work was concentrated in the central and eastern parts of the area. During July, 1986, hand sampling was done along the shores of lakes Abitibi, McDiarmid and Webster.

Prior to the 1987 field work, 257 near-surface till samples had been collected from either backhoe trenches or hand dug pits. Sonic drill programs in the Fall of 1984 and the Summer of 1985 completed a total of 102 holes. All of these drillholes were positioned beside roads. The 1984 program utilized a skid-mounted drill whereas the 1985 program used a truck-mounted drill. Drilling methodology and operations are described in Baker *et al.* (1985) and Averill *et al.* (1986). In these two programs, a total of 3903 m of drift and 176 m of bedrock were drilled. Collected from this core were 402 till, 312 glaciofluvial sand, and 97 bedrock samples. Core for holes drilled in the Larder Lake Mining Division (all of the study area except for the four westernmost townships) is stored at the Kirkland Lake Drill Core Library. Core for holes drilled in the Porcupine Mining Division (holes drilled in Sheraton, Stock, Bond, and Clergue Townships) is stored at the Timmins Drill Core Library. All bedrock and till core from the 1984 and 1985 drill programs is available for public inspection.

SAMPLING IN 1987

During February and March, 1987, a 72-hole sonic drilling program was completed in the central and southwest parts of the BRIM area. Holes were sited along existing winter roads cleared for this program and newly constructed winter roads. The 72-hole program included fill-in drilling at 65 sites which were inaccessible during summer months and detailed stratigraphic drilling at seven sites located near two previous drillholes. This program completes drilling in the west and central parts of the BRIM area.

The 1987 drill program was completed over a 42-day period, using two 12-hour shifts per day. A truck-mounted drill was utilized for the first 16 drillholes. Mild winter conditions necessitated a change to a track-vehicle (Go-Trac)-mounted drill system for the remainder of the drillholes. This set-up increased travel time between sites, required two float trips for moves which crossed pavement or were long distance, and caused the program to be charged for 68 drill standby hours. In the 72-hole program, 2613 m of drift and 146 m of bedrock were drilled. Two holes were abandoned before reaching bedrock due to broken casings. The average overburden thickness was 36 m. This compares with average overburden thicknesses of 35 m and 42 m in the 1984 and 1985 drill programs respectively.

In the selection of drill sites, the following criteria were deemed most important: an even distribution of data points over the study area, down-ice (south) of the Destor-Porcupine and Pipestone Fault Zones, over east-west oriented bedrock valleys as interpreted from airborne electromagnetic data, avoidance of esker sediments, and areas of complex or unknown bedrock geology. Sites drilled in 1987 were concentrated in Wilkie, Coulson, Warden, Milligan, Barnet, Cook, Michaud, Guibord, Beatty, Bond, and Currie Townships. Holes were also drilled in Walker, Playfair, Egan, Sheraton, Thomas, Munro, Thackeray, Harker, and Elliott Townships. Locations of all BRIM overburden holes drilled to date are illustrated in Baker and Steele (1987). A replicate hole drilled adjacent to hole 84-27 is not indicated on this map. A fence of holes about hole 84-28 was drilled for stratigraphic information.

Collected from the 1987 drill core were 408 till, 53 glaciofluvial sand, and 73 bedrock samples. Two pieces of bedrock core from some drillholes were submitted for geochemical analyses. Full analytical and stratigraphic results of the 1987 drilling program are expected to be released in data sheet and floppy diskette formats during 1988. Preliminary information on the number and distribution of visible gold grains

TABLE 075.1. SUMMARY OF SONIC DRILL PROGRAMS.

Parameter	1984	1985	1987
Time	Sept./Oct.	Aug./Sept.	Feb./March
Area	mostly farmland	mostly forest	forest & swamp
Road access	all weather farm & lumber roads	lumber roads & trails	new developed & upgraded winter roads
Drill set-up	skid-mount	truck-mount	truck-mount (16 holes) & track vehicle mount
Drill move between sites	float	self-propelled	self-propelled float for long moves
Number of 12 hour shifts per day	1	1	2
Average move distance between drill site (km)	5	6	8
Number of holes drilled	42	60	72
Total drilled (m)	1564	2598	2759
Average thickness of drift (overburden) (m)	35	42	36
Total number of days drilling	37	44	42
Average number of holes per shift	1.1	1.5	0.8

in the sonic drill core samples is available in Baker and Steele (1987).

During June, 1987, a small program of till sampling from backhoe trenches and hand dug pits was completed. Fill-in backhoe sampling was done along recently constructed mining and logging access roads, and along an old access road to Frecheville Township. In total, 17 backhoe samples were collected from Frecheville, Stoughton, Harker, Elliott, and Egan Townships. Till sampling along the shores of Lake Abitibi resulted in eight samples being collected over a four-day period. This program of backhoe and hand sampling completed the near-surface sampling of till for the BRIM project. Geochemical and mineralogical results, including gold grain counts for the 25 samples collected in 1987, will be available in data sheet format during 1988.

REGIONAL STRATIGRAPHY FROM DRILLING

Logs of the 1987 drillholes confirm the presence of three glacial packages. The fence of holes about hole 84-28 substantiated that the sediments in this hole represent the known composite stratigraphy in the BRIM area. The regional stratigraphy can be summarized, from top (youngest) to bottom, as follows:

1) Matheson package - Glaciolacustrine sediments, usually varved clay and silt, of varying thickness up to 75 m overlying till. Glaciofluvial sand occasionally occurs overlying the till. Till thicknesses are usually less than 10 m; however, up to 30 m of Matheson till has been encountered in the study area. Deposits of this package are associated with ice which advanced toward 170° azimuth.

2) A middle package - This package is restricted in areal extent and was encountered in approximately 30 percent of the drillholes and sections at the Maude Lake pit (Beatty Township). The complete stratigraphy of the package is glaciolacustrine sediments overlying glaciofluvial sand which in turn overlies till. The most common sediment sequence encountered is varved clay and silt overlying sandy silt to silty sand till. At some drill sites and at the Maude Lake pit, till was the only sediment of this package encountered. At the Maude Lake pit, till of this package is discontinuous and only occurs at the bottom of an east-west oriented bedrock depression. As determined from striae and pebble fabric data, sediments of this package are associated with ice which advanced toward 240° azimuth.

3) Lowest package - This package has been recognized in drill core from holes 84-28, 87-69, 87-70 and 87-71. Geochemical data suggests sediments of this lowest package were encountered in up to five drill holes of the 1984 and 1985 programs. Geochemical data is not presently available for the 1987 drill program. The lowest package is very restricted in areal extent and has not been seen in section. The usual stratigraphy of the package is varved clay and silt overlying till. The varved sediments are not always present. The advance direction of the ice which deposited this till is not presently known, although studies are continuing in this regard.

TABLE 075.2. SUMMARY OF SONIC DRILLING HOURS AND COSTS.

	1984	1985	1987
HOURS			
Drill	337	419	507
Move	81	67	227
Standby	-	-	68
Downtime	20	38	206
COSTS			
Total drilling costs	$164,798	$186,147	$266,367
Road building costs	-	-	$167,500
Average cost per metre	$105	$ 73	$ 97 $157 (includes road building)

NOTES

1. Drill hours include all time that drill rods and/or casings are in the hole.

2. Move hours include all tear-down, travel, and set-up time between holes.

3. Standby hours were time waiting for float. Night moves with float not allowed.

4. Drill and move hours were charged at the same rate. Standby hours were charged at a slightly lower rate. Downtime was not charged.

5. Total drilling costs include drill rig, drill crew and their accommodation, logging shack and consumables, but do not include salary or field costs for Survey personnel, core boxes, core logging or sampling.

6. Road building costs in 1987 included snow clearing of approximately 45 km of all weather roads, upgrading of approximately 100 km of pre-existing winter roads and construction of approximately 65 km of new winter roads.

7. Rates charged by the drill company did not increase during the period of the three programs.

DRILLING COSTS

The Ontario Geological Survey has completed three sonic drill programs in the Matheson area over the past four years. All of the programs were done at a reconnaissance scale, with an average move between drillholes of approximately 5 to 8 km. Each of these programs utilized a different drill set-up and encountered different weather, road and terrain conditions. These differences are summarized in Table 075.1. The drilling costs for the three programs are summarized in Table 075.2. Cost data should only be used in combination with the other information presented.

The sharp decrease in drilling costs per metre between the 1984 and 1985 programs can be attributed to a combination of two factors. Firstly, with the drill mounted on a truck in 1985, there were major savings in time and expense for the moves between drill sites. In 1984, a float was at the drill on a full-time basis adding $17,000 to the drilling cost. In 1984, the average move time between drill sites lasted 1.9 hours. This compares with the average move time of 1.1 hours with a truck mounted drill in 1985. Secondly, a much more experienced driller was on the 1985 program, increasing productivity on a metre-drilled-per-hour basis by approximately 20 percent.

The increase in drilling costs per metre between the 1985 and 1987 programs can be attributed to the higher costs and lower productivity of winter drilling. In 1987, the track-vehicle-mounted drill averaged 3.1 hours per move between sites. A float was required for 12 moves in 1987. This added float and standby charges to the progam cost. Lower productivity of winter drilling on a metre-drilled-per-hour basis is a result of many factors, these include time spent in thawing hoses, draining water tanks, setting up and tearing down the drilling enclosure, starting heating equipment and warming up engines. Longer travel times to some of the 1987 drill sites resulted in additional costs.

FUTURE SAMPLING

A winter sonic drilling program is planned for February and March, 1988. This program will be similar to the 1987 program in methodology. The drill sites of this program will be in areas of thick drift which lack

all-weather roads and have not been previously drilled during the BRIM project. Work is expected to be concentrated in the easternmost 16 townships of the BRIM area, though fill-in drilling and detailed stratigraphic drilling may be done throughout the 40-township BRIM area. This drilling program will complete the collection of till samples across the BRIM area.

PUBLICATIONS

The following maps, data sheets and reports have been published with data and information on the BRIM till sampling program as of December 1987:

Data Sheets:

1984 Sonic drillholes; Ontario Geological Survey, Maps 80759 to 80792.

1985 Sonic drillholes; Ontario Geological Survey, Maps 80845 to 80893

1984 Backhoe till samples; Ontario Geological Survey, Maps 80793 to 80796

1985 Backhoe till samples; Ontario Geological Survey, Maps 80838 to 80844

Gold Grain Maps:

1984 Drilling; Ontario Geological Survey, Map P.2736

1985 Drilling; Ontario Geological Survey, Map P.2958

1987 Drilling; Ontario Geological Survey, Map P.3097

1984 and 1985 Backhoe sampling; Ontario Geological Survey, Map P.2983

Bedrock Maps:

1984 Drilling; Ontario Geological Survey, Map P.2848

1985 Drilling; Ontario Geological Survey, Map P.2986

Open File Reports:

Rotasonic Drilling Operations (1984) and Overburden Heavy Mineral Studies, Matheson Area, District of Cochrane; Ontario Geological Survey, Open File Report 5569.

Analytical Methods, Quality Control Data, and Previously Unpublished Geochemical Results: Reconnaissance Till Sampling Program, Matheson Area, Cochrane District; Ontario Geological Survey, Open File Report 5653.

Summary of Field Work Reports:

1984 Sampling; Ontario Geological Survey, Miscellaneous Paper 119, p.295-298.

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076. A Regional Geochemical Survey in the Goudreau Lake Area, District of Algoma

John A.C. Fortescue[1] and Hubert Stahl[2].

[1]Research Geochemist, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

[2]Geological Assistant, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

INTRODUCTION

During June 1987, a small-scale regional geochemical survey, based on lake sediments and waters, was completed in an area of 500 km^2 centred on Goudreau Lake (48°17'N, 84°26'W) situated 40 km northeast of Wawa, Ontario.

The primary purpose of regional geochemical surveys is to provide information which is of direct importance in mineral exploration, either by confirming the presence of known mineralization, or by indicating other areas where mineralization may occur. The Goudreau Lake area is of particular interest in exploration at the present time, and includes a number of locations where gold deposits are being actively prospected (e.g. Kremzar deposit, Canamax Resources Incorporated, and the Magino deposit, a joint venture of Muscocho Explorations Limited and McNellen Resources Incorporated). Many areas of the Goudreau Lake region, however, are covered with surficial deposits where mineral showings are relatively rare. The Goudreau Lake survey will provide multi-element regional-level geochemical data for a 500 km^{2}area near Wawa, Ontario, and may be used as an orientation survey for regional geochemical survey coverage of the entire Wawa Greenstone Belt at some time in the future.

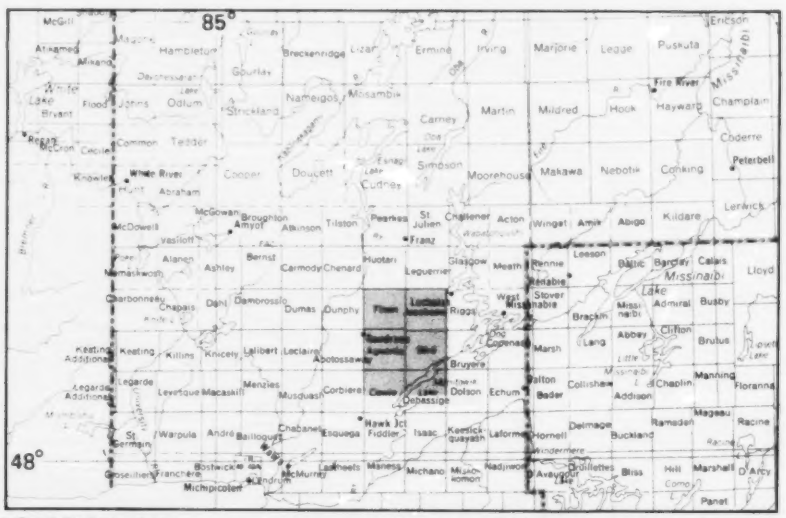
OBJECTIVES

The objectives were:

1) to collect water and lake sediment core material from most lakes and ponds accessible by helicopter in the 500 km^2 Goudreau Lake study area
2) to provide both in hard copy and in computer readable form, data for the pH, Ca, and Mg content of the water samples and the levels of Ag, Al, As, Au, Ba, Be, Br, Ca, Cr, Cu, Co, Fe, Hf, K, La, Lu, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sc, Sr, Ta, Th, Ti, U, V, W, and Zn in pre-Ambrosia lake sediment samples (i.e. sediment greater than 18 cm below the sediment surface, representing sediment free of anthropogenic inputs) collected from each sample site in the Goudreau Lake area
3) to provide a summary of the geochemical behaviour of elements which are of interest in mineral exploration in the Goudreau area. This is achieved using uni-variate, bi-variate and multivariate statistical analyses of the geochemical data obtained from the water and pre-Ambrosia lake sediment samples
4) to contribute regional geochemical data to an experimental, interdisciplinary, geoscience project of the Goudreau Lake area which involves bedrock geology, Quaternary geology, geophysics, remote sensing, and mineral deposits study information in addition to lake sediment geochemistry.

GEOLOGICAL SETTING OF THE GOUDREAU LAKE AREA

The Goudreau Lake study area includes almost all of Finan, Jacobson, Aguonie, and Bird Townships, together with the northern part of Cowie and Debassige Townships. This area is underlain almost entirely by Archean greenstones and associated rocks of the Wawa Greenstone Belt. The contact between rocks of



LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

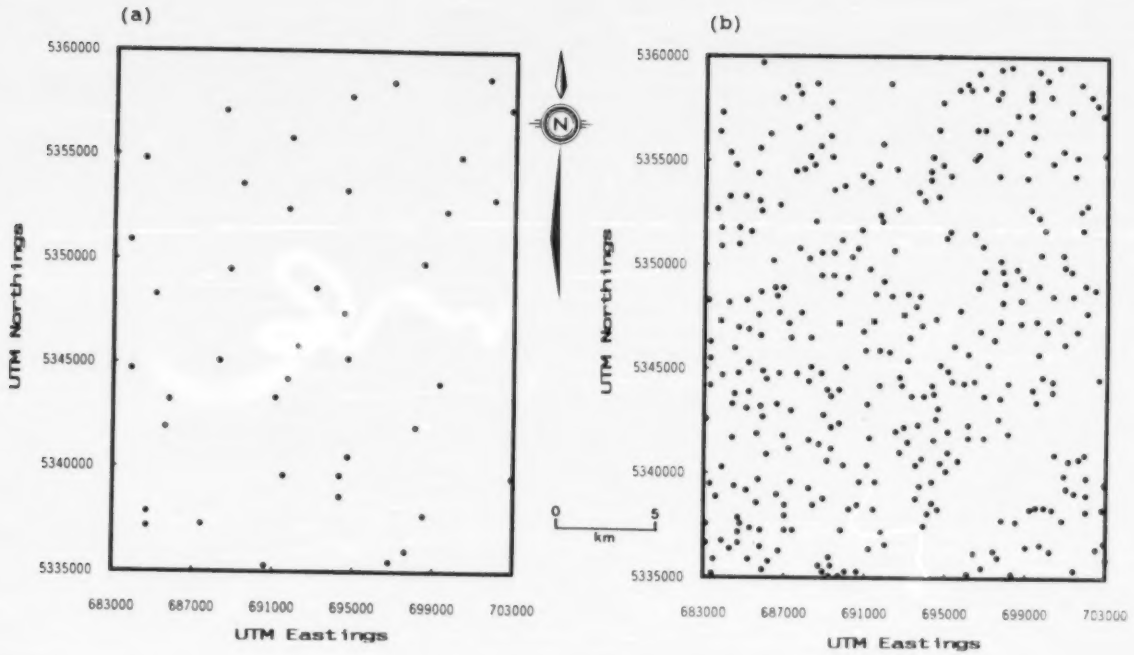


Figure 076.1. *The Goudreau Lake area showing sample point locations for the reconnaissance geochemical survey (OGS-GSC 1979) (a), and the regional geochemical survey (OGS 1987) (b).*

the Wawa Greenstone Belt and the surrounding granitic terrain is exposed in Jacobson Township in the extreme northern portion of the study area (Sage 1985). In the southern portion of the Goudreau Lake area, the contact between mafic metavolcanics and the granitic rocks occurs in Cowie and Debassige Townships.

The lithology and the structure of the greenstone belt in the Goudreau Lake area is particularly complex (Sage 1985). Sage also noted that the four principal gold properties in the area are associated with shearing and/or a narrow mafic intrusion which extends east from the village of Goudreau, parallel to the strike of the greenstone belt.

Gartner and McQuay (1979) provide an introduction to the Quaternary geology of the Goudreau area. They note that the ice advance from the north-northeast deposited a thin mantle of stony, sandy till over much of the bedrock in the area. When the ice retreated, it left a number of Quaternary deposits which mark the occurrence of ancient spillways and esker trains. The Goudreau Lake area has a number of relatively small patches of organic terrain and an area of ground moraine between the villages of Goudreau and Dubreuilville. The most significant Quaternary deposits are glaciofluvial outwash plains and eskers which occur in two parallel belts extending to the northeast from Goudreau.

Generally, the bedrock and Quaternary geological conditions in the Goudreau Lake area are favourable for a test of regional geochemistry based on lake sediments and waters.

FIELD WORK

In June of 1987, a crew of two, using a float-equipped Bell 206 helicopter, collected duplicate lake sediment cores and 1-litre water samples from 358 sample points situated in lakes and ponds in the Goudreau Lake area. The lake sediment cores were collected from 40 sample sites (i.e. 80 cores) per day and were extruded within two days of collection. The cores were extruded to provide a post-Ambrosia subsample (i.e. surface sediment from the 0 to 10 cm section of the core) and a pre-Ambrosia subsample (below 18 cm in the core). The material in the mixed zone (i.e. between 10 and 18 cm) was discarded. The pH of the waters was measured in a field laboratory prior to determination of Ca and Mg in the geoscience laboratories of the Ontario Geological Survey in Toronto.

The Goudreau Lake area lies northeast of the fume-kill area associated with the Wawa sintering plant. In this downwind direction, significant amounts of trace elements from the sintering plant are known to deposit into lakes and ponds of the area (Fortescue 1984). Consequently, the geochemical data for the Goudreau Lake survey will consist of multi-element analysis of the pre-Ambrosia samples. The pre-Ambrosia lake sediment material reflects element distribution patterns in sediment laid down prior to 1909 when the sintering plant commenced operation. The lake sediment samples have been passed to Chemex Labs Limited of Mississauga who will complete the chemical analysis under contract to the Ontario Geological Survey.

SAMPLING INTENSITY

The area included in the Goudreau Lake geochemical survey was included in a reconnaissance geochemical survey completed jointly by the Ontario Geological Survey and the Geological Survey of Canada in 1979 (OGS-GSC 1979). During that survey, the samples were collected at an average density of one per 13 km^2 (5 square miles). The sample sites included in the reconnaissance geochemical survey in the Goudreau Lake area are plotted on Figure 076.1a. The sample site locations for the regional geochemical survey described here are included in Figure 076.1b. In total, at the regional level, there are 358 sample sites within an area of 500 km^2, or 1 sample per 1.4 km^2.

Thus the regional geochemical survey intensity is approximately ten times more than that of the reconnaissance geochemical survey. This dense coverage, in combination with the use of pre-Ambrosia lake sediment sample material (which was laid down prior to modern man entering the area), analyzed for 33 major, minor, and trace elements, will provide a geochemical database of considerable interest to the mineral exploration community.

The geochemical data obtained during the Goudreau Lake survey will be released by the Ontario Geological Survey as soon as practical after it has been received, checked and, in some cases, verified for accuracy.

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077. A Regional Geochemical Survey in the Wart Lake Area, District of Algoma

John A.C. Fortescue[1] and Hubert Stahl[2]

[1]Research Geochemist, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

[2]Geological Assistant, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

This project is part of the Canada-Ontario Mineral Development Agreement (COMDA), which is a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

INTRODUCTION

In late August and early September of 1987, the first part of a three-year regional geochemical survey of the eastern end of the Batchawana Greenstone Belt, centred on Wart Lake (47°10′N, 84°8′W), 74 km north of Sault Ste. Marie, was completed. During the COMDA survey, water and lake sediment core samples were collected from a 375 km^2 area located east of, and adjacent to, a regional geochemical test area studied in 1986 (Fortescue and Stahl 1987).

The primary purpose of regional geochemical surveys is to provide information which is of direct importance in mineral exploration, either by confirming the presence of known mineralization, or by indicating other areas within which mineralization may occur. The Wart Lake area, which includes the presently active Spruce Lake gold property of Massive Energy Limited, is currently of interest to explorationists.

A reconnaissance geochemical survey completed jointly by the Ontario Geological Survey and the Geological Survey of Canada in 1978 (OGS-GSC 1979) included the Wart Lake area. A part of the Wart Lake area was also included in a small-scale geochemical survey of the Batchawana Mountain area completed by the Ontario Geological Survey in 1983 (Fortescue 1985). The aim of the current COMDA project is to provide intensive regional geochemical coverage for the entire eastern end of the Batchawana Greenstone Belt, including areas which are relatively inaccessible and poorly explored.

OBJECTIVES The objectives were:

1) to collect water and lake sediment core samples from at least one point in almost all lakes and ponds accessible by helicopter within the 375 km^2 Wart Lake study area
2) to provide both in hard copy and in computer readable form, data for the pH, Ca, and Mg content of water samples and the levels of Ag, Al, As, Au, Ba, Be, Br, Ca, Cr, Cu, Co, Fe, Hf, K, La, Lu, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sc, Sr, Ta, Th, Ti, U, V, W, and Zn in pre-*Ambrosia* lake sediment samples collected in the Wart Lake area
3) to provide a summary of the geochemical behaviour of elements of importance to mineral exploration in the Wart Lake area using uni-variate, bi-variate, and multi-variate statistical analyses of the geochemical data obtained from the water and pre-*Ambrosia* lake sediment samples

LOCATION MAP

Scale: 1:1 584 000
or 1 inch to 25 miles

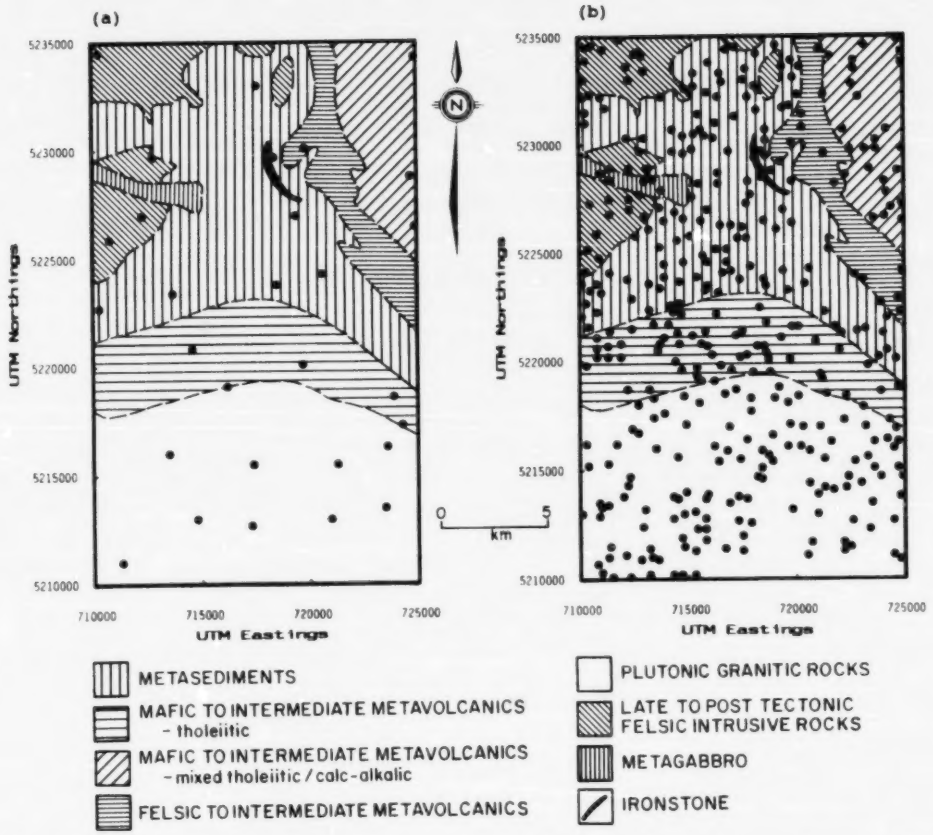

Figure 077.1. *The Wart Lake area showing the sample point locations for the reconnaissance geochemical survey (OGS-GSC 1979) (a), and the regional geochemical survey (OGS 1987) (b) in relation to the generalized geology of the area (modified from Grunsky 1984).*

GEOLOGICAL SETTING OF THE WART LAKE AREA

The Wart Lake area includes the northern part of Grenoble and Dablon Townships in the south, almost all of Davieaux and Vibert Townships plus the western part of Desbiens and Way White Townships, and extends just into Runnels and Running Townships in the extreme north (Location Map).

The regional geology of the Batchawana Synoptic Area, which includes the Batchawana Greenstone Belt and surrounding granitic terrains, was summarized by Grunsky (1984). Briefly, in the Wart Lake area (Figure 077.1), the contact between the mafic to intermediate metavolcanics of the Batchawana Greenstone Belt, which strike east/west, and the surrounding granitic rocks of the Algoma Plutonic domain to the south, angles across the middle of Davieaux Township and then turns southeast across Desbiens Township. This contact is paralleled in the extreme north of Davieaux Township and diagonally across Desbiens Township (from northwest to southeast) by a second contact between the metavolcanics in the south and metasediments in the north. In the northeastern corner of the Wart Lake area, mixed tholeiitic/calc-alkalic rocks occur which are bounded to the west by a thin band of felsic to intermediate metavolcanics. These rocks also form the northern contact of the metasediments described above. Three stocks of late to posttectonic felsic intrusive rocks are found within the metasediments. One of these, in the vicinity of Mongoose Lake, includes a relatively large mass of metagabbro. An area of regional carbonatization occurs in northern Davieaux and Desbiens Townships, striking in an east-west direction coincident with the metavolcanic belt in the west and cutting across the metasediments in the east (Grunsky 1984). The Spruce Lake gold showing, mentioned above, together with many other prospects occur in this area.

FIELD WORK

In late August and early September of 1987, an area of 375 km^2, centered on Wart Lake, was surveyed by collecting a total of 392 water and lake sediment core samples. These samples were taken by a crew of two from a float-equipped Bell 206 helicopter, at a rate of 60 sites per day. The sampling sites were generally in the central portion of the main basin of each water body, at water depths ranging from 0.5 to 44.5 m, with a mean depth of 5.8 m. Undisturbed lake

sediment cores were obtained using a gravity coring device, and 1-litre water samples were collected as surface grab samples in shallow lakes (<5 m) and as tube composites in deeper lakes.

Sediment cores were extruded into pre-*Ambrosia* (i.e. the core sediment at depths greater than 18 cm below the sediment surface) and post-*Ambrosia* (i.e. the top 10 cm of sediment from each core tube) subsamples within two days of collection. Consistent with other surveys in this series, the pre-*Ambrosia* sediment samples (i.e. sediment free of anthropogenic inputs) were used for determination of the 33 elements listed above. The water samples were forwarded to the geoscience laboratories of the Ontario Geological Survey for determination of Ca, Mg, and pH.

THE REGIONAL GEOCHEMICAL SURVEY

The Wart Lake geochemical survey was positioned to include a significant area of granitic terrain in the south, carbonatized metavolcanics and metasediments in the central part, and an area of more complex geology in the north (Figure 077.1). Figure 077.1a includes a generalized geological map plus the reconnaissance geochemical survey sample site locations included in the 1978 survey. It is evident from this sampling pattern that, within the Wart Lake Survey area, very few lake sediment samples were collected from catchments underlain by a single rock type. For example, only nine samples were collected in the granitic terrain. The enhanced regional lake sediment sampling density is indicated on Figure 077.1b. In this case, a total of 126 sample points occur in the granitic rock area and numerous others underlain by other bedrock types, for a total of 392 in the entire area. The sample density for the reconnaissance survey is approximately 1 sample per 13 km^2 compared with 1 sample per 1 km^2 in the regional survey. Careful attention to the relationship between bedrock geological contacts and limits of catchment areas for lakes and ponds will enable statistical analysis of geochemical data among catchment areas totally underlain by a particular rock type, in addition to comparisons with similar data obtained from catchments which are underlain by two or more rock types.

PROGRESS SO FAR

In September of 1987, the lake sediment samples were passed to Chemex Labs Limited for sample preparation and chemical analysis under contract. After the geochemical results are obtained from the contractor, and verified, the data will be made available in hard copy, and later, on disk for use with IBM PC's, or similar data processing equipment. The results of the preliminary statistical analysis of the data will be released later, together with other geoscience information pertinent to interpretation of the geochemical data.

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